

Standardized screening for periodontitis as an integral part of multidisciplinary management of adults with type 2 diabetes: an observational cross-sectional study of cohorts in the USA and UK

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ABSTRACT

Objective To determine prevalence and factors predictive of periodontitis by using a standardized assessment model in adults with type 2 diabetes.

Research design and methods We performed an observational cross-sectional study to determine the burden of periodontitis in adults with type 2 diabetes attending urban, ambulatory referral centers in the USA and UK. Full-mouth probing was performed and periodontitis was diagnosed based on either a low (≥ 5 mm at ≥ 1 site) or high pocket probing-depth threshold (≥ 6 mm at ≥ 1 site). Results were stratified into a five-stage schema and integrated with other clinical variables into the novel Diabetes Cross-Disciplinary Index to function as a balanced health scorecard. Corresponding demographic and routinely collected health data were obtained and comparisons were made between patients with and without periodontitis. Multivariable logistic regression was performed to identify factors predictive of the presence or absence of periodontitis.

Results Between our two cohorts, 253 patients were screened. Caucasians comprised $>90\%$ and Hispanic Americans $>75\%$ of the UK and US cohorts, respectively. Males and females were equally distributed; mean age was 53.6 ± 11 years; and 17 (6.7%) were edentulous. Of the 236 dentate patients, 128 (54.2%) had periodontitis by low threshold and 57 (24.2%) by high threshold. Just 17 (7.2%) were periodontally healthy. No significant differences in age, HbA1c, blood pressure, body mass index, low-density lipoprotein cholesterol, or smoking status (all $p > 0.05$) were identified between those with or without periodontitis (regardless of threshold) and none was found to be a significant predictor of disease.

Conclusions Periodontitis is frequent in adults with type 2 diabetes and all should be screened. Periodontal health status can be visualized with other comorbidities and complications using a novel balanced scorecard that could facilitate patient-clinician communication, shared decision-making, and prioritization of individual healthcare needs.

INTRODUCTION

People with type 2 diabetes are at higher risk of developing a number of disabling and life-threatening comorbidities and complications, including periodontal disease, than people without diabetes.¹ The type 2 diabetes pandemic and its consequences result from complex interactions of genetic and epigenetic systems within complex social structures that include many behavioral and environmental factors.^{2–3} The relationship between type 2 diabetes and periodontitis has been extensively investigated.^{4–7} Poor glucose control poses an increased risk of inflammation of the tissue surrounding the tooth (periodontium), which is a major cause of tooth loss, increased risk of cardiovascular disease, and death.^{1–4–7–8} Conversely, inflammation can exacerbate insulin resistance and poor glycemic control.³ Timely detection and management of comorbid periodontal disease in people with type 2 diabetes could optimize oral hygiene, prevent tooth loss, facilitate a healthy diet, and improve glucose control.^{1–7–9}

Global prevalence of type 2 diabetes is increasing and three in four affected adults now live in low-and-middle-income countries, which means that without effective screening and management strategies rates of oral and systemic health complications are likely to increase.¹ Assessing the status of periodontal health is a standard recommendation for delivering integrated, ‘whole-person’ diabetes care^{10–12} in the USA and elsewhere,¹ yet fewer than half of American adults with

Significance of this study

What is already known about this subject?

- ▶ Adults with type 2 diabetes and its inherent complexity, phenotypic heterogeneity, and frequent multimorbidities are at increased risk of periodontitis yet there is no consensus on international standards for its diagnosis or strategies for screening.
- ▶ Barriers to providing integrated and team-based cross-disciplinary care for adults with type 2 diabetes that is required for optimizing patient-centered health outcomes include the lack of patient and provider awareness of the relationship between oral and general health; inconsistent health messaging across all healthcare providers involved in a patient's longitudinal care; and the lack of effective communication and data-sharing between medical and dental providers.

What are the new findings?

- ▶ Our simplified approach to periodontal screening and staging of all adults with type 2 diabetes involves full-mouth periodontal probing, without the need for radiographs, and could be undertaken by either dentists, dental hygienists, or therapists and facilitate replication and scale-up in both resource-rich and resource-challenged locations around the globe.
- ▶ Results of standardized periodontal health screening in adults with type 2 diabetes can be visually integrated with other relevant clinical findings into a balanced health scorecard, such as the Diabetes Cross-Disciplinary Index (DXDI), to aid in patient-clinician communication and multidisciplinary management of comorbid chronic diseases.

How might these results change the focus of research or clinical practice?

- ▶ Integrating periodontal health status into standard comprehensive evaluations for all adults with type 2 diabetes can be effectively undertaken.
- ▶ Balanced health scorecards such as the DXDI that integrate oral and general health require additional field-testing to determine whether patient-provider communication could be optimized, patient-centered outcomes improved, and if diabetes care guidelines and policy decisions should be modified.

known diabetes have annual dental examinations.¹³ In the UK, despite 15 Healthcare Essentials that comprise the most recent guidelines for care for everyone with diabetes published by Diabetes UK, periodontal health is not included and there is no recommendation to seek oral health evaluation.¹⁴ Barriers to care integration include the lack of patient and provider awareness of the relationship between oral and general health¹⁵ as well as the lack of electronic record-linkage and data-sharing between medical and dental providers.¹⁶ Furthermore, variation between national guidelines based on single conditions and the challenges of managing patients with multimorbidity likely contribute to clinical inertia that could hinder the integration of oral and systemic health and care.^{17–21}

Diagnostic thresholds for periodontitis have been debated extensively in the periodontal literature and there is no global consensus.^{22–24} Despite variations in diagnostic criteria,^{22–25–26} one in nine adults is estimated to
















have advanced (severe) periodontitis²⁶ and people with type 2 diabetes are at an up to threefold increased risk, particularly if glycemic control is poor.⁷ Apart from the suggestion that Hispanic Americans may be, in contrast to other racial and ethnic groups, disproportionately affected with periodontitis, the true burden and clinical characteristics of periodontal disease across different adult populations with type 2 diabetes remain largely unknown.^{25–27} Indeed, genetic and population diversity, which has been suggested to underpin the phenotypic heterogeneity of diabetic complications,^{28–29} is likely to be of significant importance for the delivery of precision healthcare.³⁰

We, therefore, decided to (1) devise a simplified and standardized diagnostic screening schema to determine the prevalence of periodontitis in our two geographically and demographically disparate cohorts; (2) identify clinical variables that could reliably predict the presence or absence of periodontal disease in individual adults with type 2 diabetes; and (3) introduce, at one of our centers, a novel, cross-disciplinary 'balanced health scorecard' designed to capture a 'whole-person' view of the complexity and severity of comorbidities and complications, including periodontal disease, and promote patient-clinician communication, shared decision-making, patient engagement and adherence, and improved patient-centered health outcomes.

RESEARCH DESIGN AND METHODS

We undertook a registry-supported, observational cross-sectional cohort study of patients aged ≥18 years who were receiving care at two urban diabetes referral centers, the Western Diabetes Institute (WDI) at Western University of Health Sciences, Pomona, California, USA, and Newcastle upon Tyne Hospitals and Newcastle University (NCL), Newcastle upon Tyne, UK. Full-mouth periodontal assessment by dental care teams at their respective institutions was performed to screen for periodontitis. All patients gave written, informed consent prior to participating in the research, which was undertaken following receipt of appropriate ethical approvals.

Between September 2014 and June 2016, patients at WDI underwent periodontal screening as part of a multidisciplinary, 'one-stop-shop' evaluation within an urban, ambulatory, integrated practice unit setting,³¹ and additionally gave permission to have their past, present, and future health record information placed into the IRB-approved WDI Diabetes Research Registry. Following the evaluation, patient data were entered into the novel Diabetes Cross-Disciplinary Index (DXDI) (figure 1). DXDI plots the clinical status of 13 diabetes-relevant health domains as a 'balanced scorecard'.³² Each domain is stratified into levels 1 (health/absence of disease) through 5 (advanced disease). The domains encompass essential components of a comprehensive diabetes evaluation,¹⁰ including glycemic, cholesterol and blood pressure control; the status of kidney health,

													
1	 <7.0% (<53 mmol/mol)	 <100 mg/dL or <70 with CVD	<130mmHg	<80mmHg	No Nephropathy	No Retinopathy	Periodontal Health PD ≤ 3 mm & BOP $\leq 15\%$	LOW RISK: No risk factors present	Independent	18.5-24.9 kg/m ²	Women: ≤ 76 cm (≤ 30 in) Men: ≤ 89 cm (≤ 35 in)	No Depression PHQ-9 Score 0	Non-smoker or Stopped smoking >15 yrs
2	7.0-7.9 (54-63)	100-130	130-139	80-89	Albuminuria UACR 30-299 mg/g	Mild Non-Proliferative	Gingivitis/Incipient Periodontitis PD ≤ 4 mm & BOP $>15\%$		Modified Independent	25-29.9	Women: >76 - ≤ 83 cm (>30 - ≤ 33 in) Men: >89 - ≤ 94 cm (>35 - ≤ 37 in)	Minimal Depression PHQ-9 Score 1-4	Stopped smoking >10 yrs
3	8.0-8.9 (64-74)	131-160	140-149	90-99	Albuminuria UACR 300-999 or eGFR 30-60	Moderate Non-Proliferative	Mild-moderate Periodontitis PD ≤ 5 mm @ ≥ 1 site	MODERATE RISK: One risk factor present (neuropathy / PVD / callus / deformity)	Minimal Assist 75%	30-34.9	Women: >83 - ≤ 89 cm (>33 - ≤ 35 in) Men: >94 - ≤ 100 cm (>37 - ≤ 39.5 in)	Mild Depression PHQ-9 Score 5-9	Stopped smoking >5 yrs
4	9.0-9.9 (75-85)	161-190	150-159	100-109	Albuminuria UACR 1000-2999 or eGFR 15-29	Severe Non-Proliferative or Inactive Proliferative	Localized Advanced Periodontitis PD ≥ 6 mm @ $\leq 30\%$ of sites	HIGH RISK: Previous ulceration or amputation or >1 risk factor	Moderate Assist 50%	35-39.9	Women: >89 - ≤ 98 cm (>35 - ≤ 39 in) Men: >100 - ≤ 106 cm (>39.5 - ≤ 42 in)	Moderate Depression PHQ-9 Score 10-14	Stopped smoking >1 yr
5	≥ 10.0 (≥ 86) or Medication-induced hypoglycemia	>191	≥ 160	≥ 110	Albuminuria UACR ≥ 3000 or eGFR ≤ 15	Active Proliferative	Generalized Advanced Periodontitis PD ≥ 6 mm @ $>30\%$ of sites	ACTIVE FOOT DISEASE	Dependent High safety Risk	≥ 40 or <18.5	Women: >98 cm (>39 in) Men: >106 cm (>42 in)	Severe Depression PHQ-9 Score ≥ 15	Active smoker

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Figure 1 The Diabetes Cross-Disciplinary Index (DXDI). The DXDI is a pictorial representation of diabetes-relevant health domains, including glycemic control (HbA1c), low-density lipoprotein cholesterol (LDLc) level, systolic blood pressure (SBP), and diastolic blood pressure (DBP); kidney health (urinary albumin-to-creatinine ratio (UACR) and estimated glomerular filtration rate (eGFR)), retinal health (dilated retinal scan), periodontal health (see below), foot health, functional independence measure; as well as body mass index (BMI), waist circumference (WC), depression (patient health questionnaire 9 (PHQ 9)), and smoking status. Each domain is stratified into levels 1 (ie, health or absence of disease) through 5 (ie, severe or advanced disease). Periodontal health status was stratified in the following manner: 1, periodontal health (probing depths (PD) ≤ 3 mm and bleeding on probing (BOP) $\leq 15\%$ of sites); 2, gingivitis/incipient periodontitis (PD ≤ 4 mm and/or BOP $>15\%$ of sites); 3, mild-moderate periodontitis (PD=5 mm at ≥ 1 site); 4, localized advanced periodontitis (PD ≥ 6 mm at $\leq 30\%$ sites); and 5, generalized advanced periodontitis (PD ≥ 6 mm at $>30\%$ sites). CVD, cardiovascular disease; PVD, peripheral vascular disease.

retinal health, foot health, and functional independency; general and central adiposity measurements; as well as a depression screen and an assessment of smoking status.

At the time of our study, there was no consensus on international standards for reporting periodontitis prevalence, extent, and severity.⁵² Therefore, periodontal assessment in dentate patients included the extent of full-mouth, pocket-probing depth (PD) measurements and bleeding on probing (BOP). Periodontal health status was stratified in the following manner: DXDI 1, periodontal health (PD ≤ 3 mm and BOP $\leq 15\%$ of sites); DXDI 2, gingivitis/incipient periodontitis (PD ≤ 4 mm and/or BOP $>15\%$ of sites); DXDI 3, mild-moderate periodontitis (PD=5 mm at ≥ 1 site); DXDI 4, localized advanced periodontitis (PD ≥ 6 mm at $\leq 30\%$ sites); and DXDI 5, generalized advanced periodontitis (PD ≥ 6 mm at $>30\%$ sites). For the purpose of regression analyses, patients were also assigned to categories of either 'no periodontitis' (corresponding to DXDI scores 1 or 2) or 'periodontitis' that was further stratified by using either

a low threshold (PD ≥ 5 mm at ≥ 1 site, corresponding to DXDI score 3) or a higher threshold (PD ≥ 6 mm at ≥ 1 site, corresponding to DXDI scores 4 or 5) to define presence of periodontitis.

Patients at the NCL between January 2007 and December 2009 were being primarily managed in the diabetes clinic and underwent screening for periodontal disease at the Newcastle Dental Hospital. Demographic and clinical data of NCL patients were extracted via retrospective chart review and corresponded to the time of periodontal screening. In addition to periodontal health status, data that were evaluable and common to both WDI and NCL cohorts included age, gender, ethnicity, smoking status, glycated hemoglobin, systolic and diastolic blood pressure, body mass index (BMI), and low-density lipoprotein cholesterol (LDLc).

Statistical analyses were conducted using SAS software for Windows V.9.3. Descriptive statistics were presented as means and SD for continuous variables, and frequencies and proportions for categorical variables. Independent

Table 1 Comparisons of recorded parameters in the 'periodontitis' and 'no periodontitis' groups

	Low threshold for periodontitis (PD ≥5 mm at ≥1 site)			High threshold for periodontitis (PD ≥6 mm at ≥1 site)		
	Periodontitis n=128 (54.2%)	No periodontitis n=108 (46.8%)	p Value	Periodontitis n=57 (24.2%)	No periodontitis n=179 (75.8%)	p Value
Age (years)	52.7±9.3	53.3±12.2	0.679	52.5±8.3	53.1±11.4	0.682
HbA1c (%)	8.2±1.8	7.9±1.8	0.679	8.1±1.8	8.1±1.9	0.949
HbA1c (mmol/mol)	66.1±20.1	63.1±20.2	0.260	64.5±19.9	64.8±20.3	0.686
Systolic blood pressure (mm Hg)	139.3±21.2	138.2±20.8	0.689	140.6±21.3	138.2±20.9	0.442
Diastolic blood pressure (mm Hg)	82.2±15.9	80.6±10.4	0.355	83.2±16.1	81.0±12.8	0.343
Body mass index (kg/m ²)	33.7±7.3	34.8±8.3	0.258	34.4±6.0	34.1±8.3	0.811
Low-density lipoprotein cholesterol (mg/dL)	126.7±36.6	128.5±43.1	0.838	125.7±36.5	128.4±41.0	0.778
Current smoker, n (%)	12 (9.4%)	4 (3.7%)	0.047	5 (8.8%)	11 (6.1%)	0.127
Former smoker, n (%)	49 (38.3%)	32 (29.6%)		25 (43.9%)	56 (31.3%)	
Never smoked, n (%)	67 (52.3%)	72 (66.7%)		27 (47.4%)	112 (62.6%)	

Values expressed as means ± SD for continuous variables and n (%) for categorical variables. No significant differences were identified (all p>0.05) for comparisons between groups within low and high thresholds for defining periodontitis. PD, probing depth measurements.

samples t-tests were used to assess significance of differences for continuous variables between the periodontitis and no periodontitis groups, and χ^2 tests to compare categorical variables between groups. Multivariable logistic regression was performed to identify factors associated with the presence of periodontitis, and analysis of variance was used to compare continuous variables common to the combined WDI and NCL cohort according to periodontal DXDI score.

RESULTS

Across the two centers, a total of 253 patients with previously diagnosed type 2 diabetes (170 at WDI and 83 at NCL) underwent full-mouth periodontal assessment. Hispanic Americans comprised >75% of the WDI cohort, whereas white Caucasians comprised 94% of the NCL cohort. The combined study population contained roughly equal numbers of males and females (125 and 128, respectively) and the mean age was 53.6±11 years. A total of 146 (57.7%) reported never having smoked tobacco, and of the 107 who reported using tobacco at some point in their lives, 17 (15.9%) were currently smokers.

In total, 17 (6.7%) of the 253 screened were edentulous. Of the remaining 236 dentate patients, 128 (54.2%) were assigned a diagnosis of periodontitis based on the low threshold and 57 (24.2%) were diagnosed based on the higher threshold for periodontitis (table 1). No significant differences were identified between the 'periodontitis' and 'no periodontitis' groups (within thresholds) for age, smoking status, BMI, blood pressure, LDLc, or HbA1c (all p>0.05), and none of these factors

was identified as a significant predictor for the presence of periodontitis in multivariable logistic regression.

Furthermore, there were no significant differences between periodontal DXDI classifications with respect to evaluable clinical variables that were common to both the WDI and NCL cohorts (table 2). Table 2 also identifies that of the 236 dentate patients in our combined cohort only 17 (7.2%) were periodontally healthy.

CONCLUSIONS

The emerging global burden of comorbid type 2 diabetes and periodontal disease is likely to have significant impact on quality and longevity of life for hundreds of millions of people well into the 21st century. Given the geographically and demographically disproportionate burden of these complex, chronic diseases that are, in turn, challenged by anachronistic healthcare systems and conflicting clinical guidelines,¹¹⁰¹⁴ patients are frequently not informed of their increased risk for periodontitis and the importance of its management to optimize oral and general health. As a result, many affected adults with type 2 diabetes fall short of achieving goals for preventive practices like dental examinations,¹⁵ which further obscures the true burden of multimorbidity on the population. Indeed, novel screening and management strategies are desperately needed and, to be truly impactful, must involve practical, replicable, and scalable solutions.

In our multicenter study, respectively representative of predominantly Hispanic American and white Caucasian British patients with type 2 diabetes, we observed epidemic rates of periodontitis whether using a low (54.2%) or high (24.2%) diagnostic threshold to define

Table 2 Evaluable clinical variables common to both Western Diabetes Institute and Newcastle University cohorts according to periodontal Diabetes Cross-Disciplinary Index (DXDI) classification

	Periodontal DXDI 1 (n=17)	Periodontal DXDI 2 (n=91)	Periodontal DXDI 3 (n=71)	Periodontal DXDI 4 (n=57)	p Value
Age (years)	57.7±15.5	52.4±11.3	52.8±10.2	52.5±8.3	0.300
HbA1c (%)	7.7±1.7	8.0±1.9	8.3±1.9	8.2±2.0	0.531
HbA1c (mmol/mol)	60.2±18.5	63.7±20.5	67.2±20.2	65.7±19.9	0.519
Systolic blood pressure (mm Hg)	144.1±16.7	137.2±21.3	138.2±21.2	140.7±21.3	0.560
Diastolic blood pressure (mm Hg)	81.4±11.9	80.5±10.2	81.5±15.8	83.2±16.1	0.714
Body mass index (kg/m ²)	35.0±8.1	34.8±8.4	33.1±8.2	34.4±6.0	0.542
Low-density lipoprotein cholesterol (mg/dL)	139.2±38.2	125.1±44.7	128.2±37.9	125.7±36.5	0.841
Current smoker	0 (0%)	4 (4.4%)	7 (9.9%)	5 (8.8%)	0.142
Former smoker	3 (17.7%)	29 (31.9%)	24 (33.8%)	25 (43.9%)	
Never smoked	14 (82.4%)	58 (63.7%)	40 (56.3%)	27 (47.4%)	

None was classified as periodontal DXDI 5 in either cohort. Values expressed as means ± SD for continuous variables and n (%) for categorical variables.

Periodontal health status stratification: DXDI 1, periodontal health (PD ≤3 mm and BOP ≤15% of sites); DXDI 2, gingivitis/incipient periodontitis (PD ≤4 mm and/or BOP >15% of sites); DXDI 3, mild-moderate periodontitis (PD=5 mm at ≥1 site); DXDI 4, localized advanced periodontitis (PD ≥6 mm at ≤30% sites); DXDI 5, generalized advanced periodontitis (PD ≥6 mm at >30% sites). BOP, bleeding on probing; PD, probing depth.

the presence of disease. However, we were unable to identify, through multivariable logistic regression, any clinical predictors of periodontitis. Therefore, we concur with published guidelines that recommend periodontal screening (as an essential part of comprehensive health evaluation and management) for all adults with type 2 diabetes. Our simplified approach to screening with full-mouth periodontal probing (and not requiring the use of radiographs) could be undertaken by either dentists or task-shifted to dental hygienists and therapists.³³ Such an approach could facilitate the periodontal assessment of patients with diabetes in both resource-rich and resource-challenged locations,² and is supported by the European Federation of Periodontology manifesto on periodontal diseases and general health, which ‘calls upon all dental and health professionals to act in the prevention, early diagnosis and effective treatment of periodontal disease to combat the devastating oral and general health effects for the individual and society’.³⁴

Integrated and cross-disciplinary approaches that reorganize provider teams around patients are required for successful management of type 2 diabetes with its inherent complexity, phenotypic heterogeneity, and frequent multimorbidities.^{2 10 28 31} Integrating proper prevention and treatment of periodontitis may lower the risk of long-term diabetic complications.^{7 9} Systematic incorporation of standardized periodontal screening into routine diabetes care is a practical first step toward such integration. Management strategies that employ shared decision-making tools,^{35 36} such as a balanced health scorecard³² like DXDI, help all stakeholders to visualize the relevant yet disparate domains, gauge progress, and provide periodic feedback, could prove to

activate, motivate, and incentivize patients to pursue any needed behavioral and lifestyle changes. Balanced scorecards³² have emerged in multiple sectors, including large healthcare organizations, to more appropriately assess performance in highly specific and complex multidimensional systems. Shared decision-making aids that include condition-specific educational materials have been determined to have beneficial effects on health behavior and health status of patients facing health treatments and screening decisions as well as to promote patient-centeredness among clinicians providing specialty consultations and complex interventions.^{35 36}

Many patients express a desire that all their care providers offer consistent health messaging and facilitate access to the care that they need. Yet patients perceive that a division exists between the medical and dental professions, which has the potential to negatively impact on diabetes care.¹⁵ At one of our centers (WDI), bridges were built across multiple interprofessional divides. Periodontal data are integrated into the balanced health scorecard, DXDI (figure 1), to promote precision healthcare for people with diabetes. Periodontal health status is stratified in the following manner: 1, periodontal health (PD ≤3 mm and BOP ≤15% of sites); 2, gingivitis/incipient periodontitis (PD ≤4 mm and/or BOP >15% of sites); 3, mild-moderate periodontitis (PD=5 mm at ≥1 site); 4, localized advanced periodontitis (PD ≥6 mm at ≤30% sites); and 5, generalized advanced periodontitis (PD ≥6 mm at >30% sites). Other DXDI domains incorporate validated staging criteria for their respective aspects of health and disease. For example, the DXDI domain for kidney health reflects contemporary approaches to chronic kidney disease staging.³⁷ Adiposity was derived

from established BMI and waist circumference ranges.³⁸ The diabetic foot staging, originally based on the University of Texas classification system,³⁹ was further modified to conform with subsequent work published by the Scottish Diabetes Foot Action Group.⁴⁰ Retinopathy staging was based on international clinical severity scales⁴¹ and functional status was adapted from the validated Functional Independence Measure.⁴²

Facilitating appropriate dental referrals for those found to have periodontitis through standardized screening is just a start. Diabetes self-management education and support emphasizes the interrelationship of proper nutrition, oral health self-care, and regular physical activity. For example, at WDI the hygienist and dietitian-nutritionist can identify barriers and collaborate with the patient to devise an individualized meal plan that accounts for their oral health status, including the presence of any loose teeth and objective evidence of periodontitis as well as any complaints of sore gums and painful chewing. The hygienist, nutritionist, and physical therapist, often on the same follow-up appointment day, can work in concert with each patient to combine activities and behavioral management strategies.

However, there are several limitations of this study that warrant consideration when interpreting the results. While all attempts were made to standardize periodontal assessments with simplified and reproducible, quantitative criteria, the lack of universally agreed upon standards for diagnosing the presence, extent, and severity of periodontitis raises the possibility that its true prevalence was either overestimated or underestimated in our study. Second, while we were able to control for thoroughness and reliability of periodontal screening data at both WDI and NCL, the need to retrieve historical chart data for other corresponding clinical variables for the patient group at NCL could have affected our multivariable analysis, therefore limiting our ability to identify factors that were significantly associated with the presence of periodontitis. Finally, our study was not designed to assess the utility and impact of DXDI. Although anecdotal feedback from clinicians and patients suggested that DXDI could aid patient-clinician communication and engagement over time, this remains to be proven.

Therefore, more research is now required to investigate several remaining open questions. First, the impact of DXDI on the health outcomes of patients with type 2 diabetes and its associated comorbidities and complications remains to be defined. It seems intuitive that the ranking and visualization of multiple diabetes-relevant health domains would enable team-based discussion around the sequencing and prioritization of care for each patient.⁴³ Yet, it would be important to know if DXDI helps providers from multiple disciplines to communicate consistent messaging to patients and improve their access to oral healthcare.¹⁵ Furthermore, while DXDI provides a composite view of the complexity and severity of diabetes and multimorbidity in our particular study population, its applicability to other ethnic, racial, and cultural groups

would require additional field-testing and pilot-testing to determine whether it optimizes communication and facilitates the delivery of improved patient-centered outcomes. With that in mind, a modified version of DXDI was incorporated in 2015 into the Scottish Care Information Diabetes Collaboration (SCI-Diabetes) platform, in which the complete diabetes record can be viewed by any National Health Service healthcare professional involved in a patient's care.⁴³ It should also be noted that, at the time of this writing, data on periodontal health are not accessible through the SCI-Diabetes platform. Second, though our simplified approach to periodontal assessment was designed to enable effective multidisciplinary screening and use of the DXDI in real-world clinical settings across the globe (without requiring detailed measurements of periodontal attachment loss or the use of dental radiographic equipment that is not always readily available),² validation of both through large-scale field studies is needed to help determine whether its sensitivity and specificity within diverse populations are clinically and epidemiologically acceptable. Indeed, issues of interoperator and technical skill variability may pose limits on the widespread applicability of our simplified approach even as it serves to mitigate cost and access barriers. Further study is warranted to assess those potential limitations. Third, determining the real burden of periodontitis²⁴ and other comorbid chronic diseases, such as chronic obstructive pulmonary disease and heart failure, in people with type 2 diabetes, raises the possibility that new domains could be further added to DXDI to assist in the management of patients with multimorbidity.^{18 20 35 44 45} In turn, the interrelationships and complexities that impact health outcomes might be better understood and serve to inform guidelines and policy decisions around optimal allocation of scarce resources.^{2 17 30} How periodontitis impacts diverse populations in different geographical contexts and how treatment affects the complex natural history of diabetes and its complications remain to be determined.

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Competing interests PMP reports grants from Dunhill Medical Trust, UK, and the UK Department of Health during the conduct of the study. ASP is the inventor of DXDI.

Patient consent Obtained.

Ethics approval Institutional Review Board of Western University of Health Sciences Protocol #13/IRB/017; UK Research Ethics Service Sunderland Ethics Committee #06/Q0904/8. All data analyzed and reported in this study are anonymized as per IRB protocol.

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