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Tooth loss during supportive periodontal care: A prospective study

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Abstract

Aim: To assess periodontal stability and the association between tooth- and patient-related factors and tooth loss during supportive periodontal care (SPC).

Materials and Methods: A prospective observational study was carried out on previously treated periodontitis patients followed up for 5 years in SPC. The risk profile (low, moderate, high) of each patient based on periodontal risk assessment (PRA) scoring at baseline was evaluated, and tooth loss rates were analysed.

Results: Two hundred patients were included in the study, and 143 had 5-year follow-up data available for analysis. The overall annual tooth loss per patient was 0.07 ± 0.14 teeth/patient/year. Older age, smoking, staging and grading were associated with increased tooth loss rates. Most patients whose teeth were extracted belonged to the PRA high-risk group. Both PRA and a tooth prognosis system used at baseline showed high negative predictive value but low positive predictive value for tooth loss during SPC.

Conclusions: Overall, the tooth loss rate of periodontitis patients in this prospective cohort study under SPC in private practice was low. Both tooth-based and patient-based prognostic systems can identify high-risk cases, but their positive predictive value should be improved.

KEYWORDS
maintenance, periodontitis, prognosis, progression, tooth loss

Clinical Relevance

Scientific rationale for study: Very few prospective studies have yet assessed the associations between patient and tooth prognostic and tooth loss during supportive periodontal care.

Principal findings: Tooth loss is minimal during supportive periodontal care, and patient- and tooth-prognostic factors can identify high-risk patients and teeth.

Practical implications: The use of patient- and tooth-prognostic systems is encouraged during supportive periodontal care, but bearing in mind that only a small proportion of teeth are lost during 5 years.

1 | INTRODUCTION

Very few prospective studies have investigated tooth loss risk and patient-specific factors during supportive periodontal care (SPC) (L. Chambrone et al., 2010; Muller Campanile et al., 2019; Pretzl et al., 2018). Smoking, non-compliance with SPC, diabetes mellitus, age, high plaque score, average clinical attachment level (CAL), initial tooth prognosis, initial diagnosis and periodontitis severity have been shown to be associated with risk of tooth loss in many retrospective studies (L. Chambrone et al., 2010; Costa et al., 2012; Eickholz et al., 2008; Matuliene et al., 2010; McGuire & Nunn, 1996; Nibali et al., 2017; Page et al., 2002). Site-specific factors such as tooth type, baseline bone loss, furcation involvement, tooth mobility, mean probing pocket depth and CAL, bleeding on probing, angular bony defects and endodontic pathology have been identified as risk factors for tooth loss (L. A. Chambrone & Chambrone, 2006; Graetz et al., 2015; Helal et al., 2019; Hirschfeld & Wasserman, 1978; Nibali et al., 2016; Papapanou & Wennstrom, 1991; Pretzl et al., 2008).

Identifying the risk of tooth loss for both patients and individual teeth is a crucial step as it helps in the development of an effective treatment plan and enables clinicians to make informed decisions. Several patient-based risk assessment systems have been developed for this purpose, but their efficacy remains uncertain (Lang & Bartold, 2018). A prospective study design is considered the ideal approach to investigating the risk factors for tooth loss, as all relevant risk factors and outcomes are recorded systematically, accurately and uniformly, and compliance with and loss to follow-up are accounted for, reducing the risk of bias compared with a retrospective design. Therefore, this study aimed at assessing the associations between tooth- and patient-related factors (individually and combined in prognostic systems) and tooth loss during SPC over 5 years in a cohort of patients with periodontitis undergoing maintenance care in a private practice setting in the UK.

2 | MATERIALS AND METHODS

2.1 | Patient population

Two hundred consecutive patients enrolled in an SPC programme were recruited from author LN's patient list in three private periodontal practices in London and Bishop's Stortford, United Kingdom. All patients had been referred to author LN for periodontal care. Ethics approval for the analysis was sought from The London and City Ethics Committee, which gave permission for the study to be carried out as service evaluation (reference no. 14 LO 0629). Each patient gave written consent to take part in the study. The study was registered on clinicaltrials.gov (NCT02091258). STROBE guidelines were followed for reporting the study (von Elm et al., 2008). Patient visits took place from August 2014 to June 2021. Some of the patients had already been included in a retrospective study as part of the same service evaluation (Nibali et al., 2017). Data relative to a subset of the prospective population have been reported previously (Saydzai et al., 2022). The following inclusion criteria were considered for patient recruitment: (i) diagnosis of chronic periodontitis (Lindhe et al., 1999) with interproximal attachment loss ≥3 mm in at least two non-adjacent teeth (Tonetti et al., 2005); (ii) at least two sites with ≥5 mm probing pocket depths (PPDs) and radiographic evidence of bone loss ≥20% of root length at first visit; (iii) treated by author LN with non-surgical periodontal treatment with or without subsequent periodontal surgeries; (iv) willing to give written informed consent for study participation; and (v) willing to undergo SPC as per standard of care for at least 5 years.

Exclusion criteria were (i) serious medical history that prevented patients from undergoing dental treatment; (ii) conditions requiring prophylactic antibiotic coverage prior to invasive dental procedures; (iii) current alcohol or drug abuse; (iv) self-reported pregnancy or lactation; and (v) other severe acute or chronic medical or psychiatric condition or laboratory abnormality that may compromise trial participation and/or interpretation of trial results.

2.2 | Pre-study periodontal therapy

Initial periodontal therapy, prior to study baseline, consisted of case presentation and patient motivation, oral hygiene instruction (OHI) and non-surgical supra- and sub-gingival professional mechanical plaque removal followed by, as required, periodontal surgery including access flap, regenerative and mucogingival surgery, and endodontic and prosthetic treatment if necessary. Some patients received adjunctive therapy including systemic or local antibiotics. Teeth that were considered irrational to treat according to the initial treatment plan were extracted during the initial periodontal therapy. Patients were then assessed 3–6 months later and, if periodontal conditions were considered stable, entered SPC.

2.3 | Clinical examinations

Following consent, at baseline, self-reported patient medical and smoking history was checked. The following periodontal measurements were taken by author LN at six sites/tooth: dichotomous full mouth plaque scores (FMPS) (Guerrero et al., 2005), full mouth PPD, recession (REC) of the gingival margin from the cemento-enamel junction (CEJ), full mouth bleeding on probing (FMBS) (Ainamo & Bay, 1975), tooth mobility (Laster et al., 1975) and furcation involvement (Hamp et al., 1975; Tarnow & Fletcher, 1984). CAL was calculated as PPD + REC. If the gingival margin was coronal to the CEJ, a negative value was given, corresponding to the number of mm the gingiva was coronal to the gingival margin. Dental radiographs of each patient were obtained as necessary for diagnosis and treatment planning purposes at this visit. Disease risk was calculated at baseline using the periodontal risk assessment (PRA) (Lang & Tonetti, 2003), modified to exclude genetic factors (Persson et al., 2003).

2.4 | Assignment of tooth prognosis

Tooth prognosis was prospectively assigned to all teeth with available clinical and radiographic data. A Tooth Prognosis Score (TPS)

previously introduced by our research group (Nibali et al., 2017) was used for assigning tooth prognosis (see Supplemental Material 1). Tooth prognosis was categorized as 'good', 'fair', 'questionable' and 'unfavourable'.

2.5 | SPC protocol

SPC followed an individualized interval of 3–12 months and consisted of medical and dental history updates, pocket charts, oral hygiene re-instructions and motivation and supra- and sub-gingival debridement (under local anaesthesia when necessary). Study visits including full periodontal charting as described above were carried out every 12 months. SPC recall intervals were individualized based on PRA combined with patient preferences. SPC visits were carried out by author LN. If deterioration in periodontal parameters was detected, further treatment (including periodontal surgeries, extractions, or endodontic therapy) was carried out. Progression of periodontitis was defined as the presence of two or more teeth demonstrating longitudinal loss of proximal attachment of ≥3 mm (Tonetti et al., 2005). When progression was detected, further treatment, usually consisting of sub-gingival debridement under local anaesthesia, was carried out. Tooth loss due to periodontal disease progression was also accounted for disease progression in this study.

2.6 | Radiographic analyses

Periapical radiographs from all patients included in the study were screened, entered in a dedicated database, transferred into a dedicated software system (Xposeit version 3.01; Torben Jørgensen, Lystrup, Denmark) and analysed by one designated examiner (author AA) at all measurable sites (mesial and distal) to calculate the percentage of bone loss by root length, as described before (Nibali et al., 2011).

2.7 | Examiner calibration

Reproducibility of clinical and radiographic examinations and prognosis assignment is described in Supplemental Material 2.

2.8 | Sample size calculation and statistical analysis

The sample size for this study was calculated based on the example of smoking as a risk factor for tooth loss. Assuming a tooth loss rate of 0.1 tooth/year (Hirschfeld & Wasserman, 1978; Nibali et al., 2013), we hypothesized an average of 0.5 tooth loss over 5 years in non-smokers (±0.5) and 0.75 in smokers. Using a two-sided unpaired *t*-test, a total sample size of 168 cases would have 90% power to detect a difference in tooth loss due to smoking at a 5% significance level. The final sample size was 200 patients, to account for an estimated 15% dropout rate.

The primary outcome was tooth loss, and potential associations between factors such as age, gender, smoking, body mass index (BMI), medical history, previous months of SPC and initial disease severity on tooth loss were analysed by univariate analysis for possible bias. Specific tests used are described in table footnotes. Analysis on prognostic accuracy for both PRA and TPS, including the assessment of sensitivity, specificity and predictive values, as well as area under the ROC curve, was performed. Logistic regression analysis was performed to evaluate the association between tooth loss and both scores, adjusting for age, gender, BMI and previous months of SPC. Results were presented as odds ratios (ORs). Zero-inflated Poisson regression analysis was performed to calculate associations with the number of teeth lost per patient during SPC. Data were presented as incidence rate ratio.

Multilevel logistic and survival regression analyses, considering the presence of multiple teeth per patient, were used to assess the association between tooth loss and TPS, PPD, CAL, bone loss, restorations, endodontic treatments, abutments, periapical lesions, intrabony defects, furcation involvement and tooth mobility. Analyses were adjusted for age, gender, smoking, diabetes mellitus, FMPS, FMBS and follow-up time. Two-sided tests were used for all analyses, and the level of statistical significance was set at 5%. All statistical analysis procedures were performed with Stata 14 (StataCorp LLC, College Station, TX, USA).

3 | RESULTS

3.1 | Baseline characteristics

The 'baseline' of this study corresponds with the time when patients signed the consent form and were officially enrolled in the study. Data relative to the first patient visit (before start of active periodontal therapy) as well as at the start of the study (baseline) are reported in Table 1. Most patients had been initially diagnosed with severe periodontitis (89%) (Page & Eke, 2007). According to the 2018 classification, most patients were diagnosed as Stage III (87%), with a lower proportion of Stage IV periodontitis (13%), and most patients were assigned a Grade B (61%), followed by Grade C (39%) (Tonetti et al., 2018), based on CAL/age ratio and grade modifiers at initial presentation. The extent of periodontitis cases was equally distributed (50% localized and 50% generalized). One-hundred and forty-six patients had already started SPC before the 'baseline' appointment of the present prospective study, for an average of 52.3 ± 33.4 months in SPC per patient. At the study baseline, 90 patients (45%) were categorized as low risk, 88 (44%) as moderate risk and 22 (11%) as high risk based on the PRA system (Lang & Tonetti, 2003).

Table 1 describes the baseline clinical data of the teeth in the 200 patients ($n = 4983$). According to Nibali et al. (2017) TPS, the prognosis was good for 61.1% of teeth, fair for 29.0%, questionable for 9.3% and unfavourable for 0.6%. Thirty-nine patients (27.7%) had met the end points of the therapy (EFP S3 guideline) (Sanz et al., 2020), while 102 (65.0%) had met the 'controlled periodontitis' criteria (Feres et al., 2020) at the study baseline. Supplemental

TABLE 1 Demographic and clinical baseline data of patients and teeth included in the study.

Variables	All patients included at baseline ($n = 200$)	Patients with 5-year data ($n = 143$)
Demographic variables		
Age (years), mean ± SD	55.8 ± 9.2	56.0 ± 8.7
Weight (kg), mean ± SD	70.3 ± 15.5	69.7 ± 15.4
BMI, mean ± SD	24.7 ± 4.1	24.6 ± 4.3
Gender (female), *n* (%)	132 (66%)	98 (68.5%)
Ethnicity (White), *n* (%)	192 (96%)	137 (95.8%)
Smoking		
Never smoker	101 (50.5%)	72 (50.3%)
Former smoker	71 (35.5%)	51 (35.7%)
Current smoker	28 (14%)	20 (14.0%)
Diabetes mellitus (yes), *n* (%)	7 (3.5%)	3 (2.1%)
Hypertension (yes), *n* (%)	34 (17%)	20 (14.0%)
Dyslipidaemia (yes), *n* (%)	20 (10%)	13 (9.1%)
Cardiovascular diseases (yes), *n* (%)	8 (4%)	8 (5.6%)
Depression (yes), *n* (%)	5 (2.5%)	3 (2.1%)
Self-reported family history of periodontitis (yes), *n* (%)	72 (36%)	49 (36.6%)
Clinical variables		
Number of teeth, mean ± SD	25.6 ± 3.6	25.5 ± 3.7
Number of teeth (except 8s), mean ± SD	24.6 ± 3.4	24.6 ± 3.6
FMPS (%), mean ± SD	12.5 ± 10.1	12.3 ± 9.6
FMBS (%), mean ± SD	5.4 ± 4.1	5.4 ± 4.0
Number of PPDs >4 mm, mean ± SD	3.7 ± 4.3	3.7 ± 4.0
Average PPD, mean ± SD	2.2 ± 0.3	2.2 ± 0.3
Average REC, mean ± SD	0.8 ± 0.7	0.8 ± 0.6
PRA classification, *n* (%)		
PRA low risk	90 (45%)	64 (44.7%)
PRA moderate risk	88 (44%)	65 (45.5%)
PRA high risk	22 (11%)	14 (9.8%)
Compliant with all follow-up visits (yes), *n* (%)	102 (51%)	100 (69.9%)
Previous months in SPC, mean ± SD	52.3 ± 33.4	57.3 ± 32.1
Tooth-level variables ($n = 4893$)		
Location (Ant/Post), *n* (%)		
Anterior	1716 (42.9%)	
Posterior	2288 (57.1%)	
Location (Max/Mand), *n* (%)		
Maxillary	2002 (50.0%)	
Mandibular	2002 (50.0%)	
Deepest PPD (mm), mean ± SD	2.9 ± 1.1	
Deepest CAL (mm), mean ± SD	4.1 ± 1.8	
Deepest Bone Loss (%), mean ± SD	29.6 ± 43.7	
Furcation defects in molars, *n* (%)		
No furcation defect	585 (48.4%)	
Class I	398 (32.9%)	
Class II	111 (9.2%)	
Class III	115 (9.5%)	

TABLE 1 (Continued)

Variables	All patients included at baseline ($n = 200$)	Patients with 5-year data ($n = 143$)
Prognosis score (Nibali et al., 2017)[a]		
Good	2521 (61.1%)	
Fair	1198 (29.0%)	
Questionable	384 (9.3%)	
Unfavourable	25 (0.6%)	

Abbreviations: BMI, body mass index; CAL, clinical attachment level; FMBS, full mouth bleeding score; FMPS, full mouth plaque score; PRA, periodontal risk assessment; PPD, probing pocket depth; REC, recession; SPC, supportive periodontal care.
[a]Prognosis score could be assigned only to 4128 teeth.

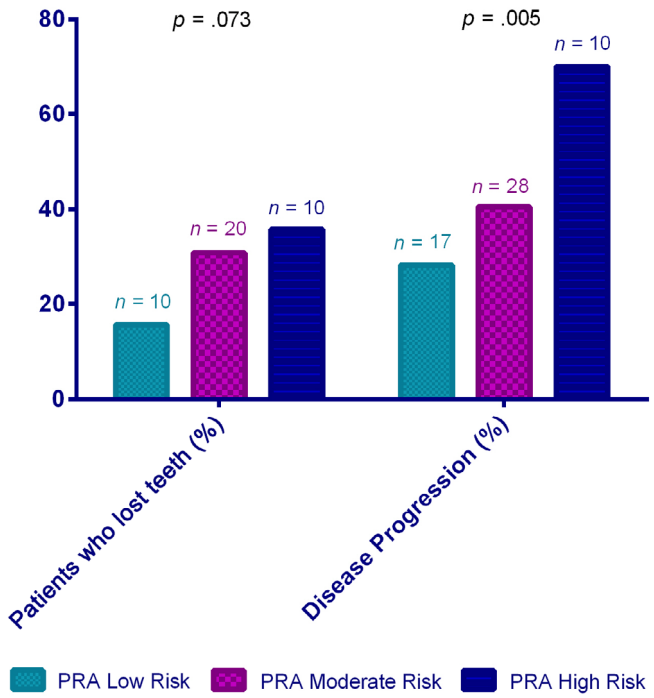

FIGURE 1 Number of patients with 5-year follow-up ($n = 143$) who lost teeth, and had disease progression classified by baseline periodontal risk assessment (PRA) profile. Of 143 patients, 40 had lost teeth during follow-up. 15.6% of them were categorized as low risk, 30.8% as moderate risk and 35.7% as high risk based on the PRA system. Fifty-five out of the 143 patients experienced disease progression (Tonetti & Claffey, 2005). When compared with different PRA scores, patients who experienced disease progression had increased higher risk profiles (28.2%, 40.5% and 70%).

Material 3 reports patient characteristics at their first presentation before any periodontal treatment (collected retrospectively).

3.2 | Patient flow

A decreasing number of patients attended follow-up study visits, from baseline ($n = 200$) to year 5 ($n = 143$) (Supplemental Material 4). One hundred and eighty-five patients had at least one follow-up visit. Nine patients attended a 5-year visit by a different operator in the same study setting, providing tooth loss data, resulting in 143 patients who had 5-year tooth loss data (28.5% loss to follow-up). Reasons for dropout were known for all 57 patients: they had moved away or could not attend due to the COVID-19 pandemic. A comparison of socio-demographic and clinical variables between dropouts and patients with 5-year data is presented in Supplemental Material 5. Table 1 shows the baseline demographic and clinical characteristics of the 143 patients with 5-year data, the majority (69.9%) of whom were compliant with all follow-up visits. During the study, 9 patients reported a cancer diagnosis (in four cases breast cancer, one colon cancer, one ovarian, one nasal carcinoma, one lymphoma and one bladder cancer), while 27 patients reported other changes in medical history. Three patients quit smoking during the study, while one started smoking again. The number of SPC visits over 5 years increased with increased PRA score, from low-risk patients (average 7.2 ± 2.5 visits, equivalent to 8 monthly) to moderate-risk patients

(average 8.8 ± 3.8 visits, equivalent to 7 monthly) to high-risk patients (average 10.5 ± 4.4 visits, equivalent to 6 monthly).

3.3 | Tooth loss and disease progression at patient level

When all patients with 5-year follow-up were considered ($n = 143$), 35 patients (24.5%) lost 55 teeth during SPC and 55 patients (38.5%) showed disease progression (Figure 1). The overall annual tooth loss per patient was 0.08 ± 0.15 teeth/patient/year (0.02 ± 0.06 teeth/patient/year due to periodontal reasons). The patients who experienced disease progression during SPC were significantly older ($p = .049$) and more likely to be current or former smokers ($p = .002$) than those who did not lose teeth (Table 2). Tooth loss rates in patients, according to their PRA profile, are presented in Supplemental Material 6. Patients with Stage IV periodontitis had a higher likelihood of tooth loss than those with Stage III ($p = .004$) periodontitis. Similarly, Grade C patients had a higher likelihood of tooth loss than those with Grade B ($p = .002$). No significant differences were found for BMI, gender, ethnicity or medical history. Disease progression was associated with age ($p = .049$), Page and Eke classification ($p = .003$), and periodontitis grade ($p = .007$). Also, regression analysis showed a higher OR for disease progression in patients with PRA high risk (OR = 7.13, 95% confidence interval [CI]: 1.85–27.53,

TABLE 2 Comparisons of patient-level variables considering tooth loss and disease progression during supportive periodontal care (SPC) ($n = 143$).

	Tooth loss during SPC			Disease progression during SPC		
Variables	**No ($n = 108$)**	**Yes ($n = 35$)**	***p*-Value**	**No ($n = 88$)**	**Yes ($n = 55$)**	***p*-Value**
Age (years), mean ± SD	55.4 ± 9.06	57.5 ± 7.50	.224[a]	54.8 ± 8.46	57.8 ± 8.91	.049[a]
BMI, mean ± SD	24.4 ± 4.0	25.3 ± 5.1	.276[a]	24.3 ± 4.3	25.1 ± 4.2	.296[a]
Gender, *n* (%)						
Male	32 (71.1%)	13 (28.9%)	.406[b]	25 (55.6%)	20 (44.4%)	.319[b]
Female	76 (77.6%)	22 (22.5%)		63 (64.3%)	35 (35.7%)	
Ethnicity, *n* (%)						
White	104 (75.9%)	33 (22.1%)	.610[b]	84 (61.3%)	53 (38.7%)	.729[b]
Asian	3 (60%)	2 (40.0%)		3 (60%)	2 (40%)	
Mixed	1 (100%)	0 (0%)		1 (100%)	0 (0%)	
Smoking, *n* (%)						
Never smoker	60 (83.3%)	12 (16.7%)	.002[b]	48 (66.7%)	24 (33.3%)	.287[b]
Former smoker	39 (76.5%)	12 (23.5%)		27 (52.9%)	24 (47.1%)	
Current smoker	9 (45.0%)	11 (55.0%)		13 (65.0%)	7 (35.0%)	
Medical history, *n* (%)						
Yes	42 (72.4%)	16 (27.6%)	.475[b]	54 (63.5%)	31 (36.5%)	.554[b]
No	66 (77.7%)	19 (22.3%)		34 (58.6%)	24 (41.4%)	
Previous months in SPC, mean ± SD	46.9 ± 36.0	39.8 ± 42.3	.337[a]	40.5 ± 36.5	52.9 ± 38.4	.055[a]
Page and Eke classification, *n* (%)						
Moderate	13 (100%)	0	.032[b]	13 (100%)	0 (0%)	.003[b]
Severe	93 (73.2%)	34 (26.8%)		74 (58.3%)	53 (41.7%)	
Periodontitis stage, *n* (%)						
III	98 (79.7%)	25 (20.3%)	.004[b]	79 (64.2%)	44 (35.8%)	.101[b]
IV	10 (50.0%)	10 (50.0%)		9 (45.0%)	11 (55.0%)	
Periodontitis grade, *n* (%)						
B	72 (84.7%)	13 (15.3%)	.002[b]	60 (70.6%)	25 (29.4%)	.007[b]
C	36 (62.1%)	22 (37.9%)		28 (48.3%)	30 (51.7%)	
Periodontitis extension, *n* (%)						
Localized	57 (77.0%)	17 (23.0%)	.665[b]	50 (67.6%)	24 (32.4%)	.125[b]
Generalized	51 (73.9%)	18 (26.1%)		38 (55.1%)	31 (44.9%)	

Abbreviation: BMI, body mass index.
[a]Student's *t*-test.
[b]Chi-squared test.

$p = .004$) and periodontitis Grade C (OR = 2.86, 95% CI: 1.33–6.14, $p = .007$) (Supplemental Material 7).

When patients with any study follow-ups ($n = 185$) were considered, a total of 65 teeth were extracted excluding third molars, 41 of which were molars (25 maxillary/16 mandibular), 13 premolars (12 maxillary/1 mandibular), 8 incisors and 3 canines (5maxillary/6 mandibular) (annual tooth loss 0.07 ± 0.14 teeth/patient/year). Reasons for extractions were fracture ($n = 17$), periodontal disease ($n = 17$, usually linked with increase in mobility), endodontic pathology ($n = 13$), caries ($n = 8$), pain ($n = 5$) and orthodontic purpose ($n = 5$). No difference in clinical variables was found between patients who were already in SPC and those who entered SPC at the study baseline (Supplemental Material 8).

3.4 | Patient-level analysis of factors associated with tooth loss

The multivariate analysis ($n = 143$) showed that patients with a worse PRA prognosis had higher odds of experiencing tooth loss (OR = 1.93, 95% CI: 1.03–3.58, $p = .038$) than those with a better prognosis (Table 3). Both staging (IV vs. III) (OR = 4.09, 95% CI: 1.42–11.75, $p = .009$) and grading (C vs. B) (OR = 4.13, 95% CI: 1.75–9.71, $p = .001$) were also associated with approximately four times higher odds of tooth loss during SPC. The PRA showed sensitivity of 66.7%, specificity of 50.0%, positive predictive value of 30.0% and negative predictive value of 82.4% for tooth loss during SPC, and the ROC curve showed an area under the curve of 0.5913 (Figure 2). No difference in tooth loss or disease progression rates was detected between patients who attended all study visits ($n = 100$) and patients who did not ($n = 43$) (data not reported in tables).

3.5 | Tooth loss at tooth-level analysis of factors

Multilevel logistic regression (Table 4) showed that the deepest PPD and the deepest CAL were both significantly associated with increased odds of tooth loss (OR = 1.92, 95% CI = 1.57–2.35, $p < .001$ and OR = 1.55, 95% CI = 1.35–1.79, $p < .001$, respectively). Additionally, teeth that were restored, had root canal treatments or presented intrabony defects had significantly higher odds of loss. Both degree II mobility and furcation defects were also significantly associated with tooth loss, with Class III furcation defects showing the highest odds (OR = 5.65, 95% CI = 1.79–17.83, $p = .003$). The Nibali et al. (2017) TPS showed increasing OR values of tooth loss with

TABLE 3 Logistic (odds ratio [OR]) and zero-inflated Poisson (incidence rate ratio [IRR]) regression analyses of tooth loss at patient-level data.

	Patients with any study follow-up ($n = 185$)				5-year tooth loss data available ($n = 143$)			
	OR (95% CI)	*p*-Value	IRR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value	IRR (95% CI)	*p*-Value
Total tooth loss								
PRA prognosis	1.75 (1.02–2.99)	.042	0.97 (0.67–1.42)	.887	1.93 (1.03–3.58)	.038	0.97 (0.63–1.50)	.885
PRA low risk	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
PRA moderate risk	1.67 (0.76–3.68)	.204	0.98 (0.56–1.73)	.952	2.13 (0.87–5.17)	.096	0.90 (0.48–1.70)	.754
PRA high risk	3.14 (1.00–9.84)	.050	0.94 (0.43–2.06)	.882	3.45 (0.91–13.16)	.070	0.97 (0.40–2.37)	.954
Periodontitis stage								
III	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
IV	4.49 (1.69–11.92)	.003	1.20 (0.67–2.15)	.536	4.09 (1.42–11.75)	.009	1.22 (0.67–2.24)	.517
Periodontitis grade								
B	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
C	3.73 (1.73–8.05)	.001	1.01 (0.59–1.73)	.966	4.13 (1.75–9.71)	.001	0.94 (0.53–1.69)	.845
Periodontal tooth loss								
PRA prognosis	3.51 (1.53–8.06)	.003	2.27 (1.06–4.84)	.034	4.58 (1.73–12.12)	.002	2.61 (1.08–6.34)	.034
PRA low risk	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
PRA moderate risk	4.11 (0.82–20.61)	.086	2.84 (0.59–13.64)	.095	8.93 (1.07–74.21)	.043	4.34 (0.92–1.08)	.992
PRA high risk	12.87 (2.24–73.99)	.004	5.62 (1.06–29.91)	.043	27.06 (2.61–280.21)	.006	8.81 (0.97–79.65)	.053
Periodontitis stage								
III	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
IV	3.80 (1.14–12.68)	.030	1.46 (0.48–4.42)	.507	3.23 (0.86–12.15)	.082	1.30 (0.42–4.07)	.651
Periodontitis grade								
B	(Reference)	-	(Reference)	-	(Reference)	-	(Reference)	-
C	2.80 (0.93–8.46)	.067	1.17 (0.39–3.46)	.781	2.70 (0.82–8.87)	.101	1.02 (0.33–3.18)	.969

Note: All models adjusted for gender, age, body mass index and previous months in supportive periodontal care.
Abbreviations: CI, confidence interval; PRA, periodontal risk assessment.

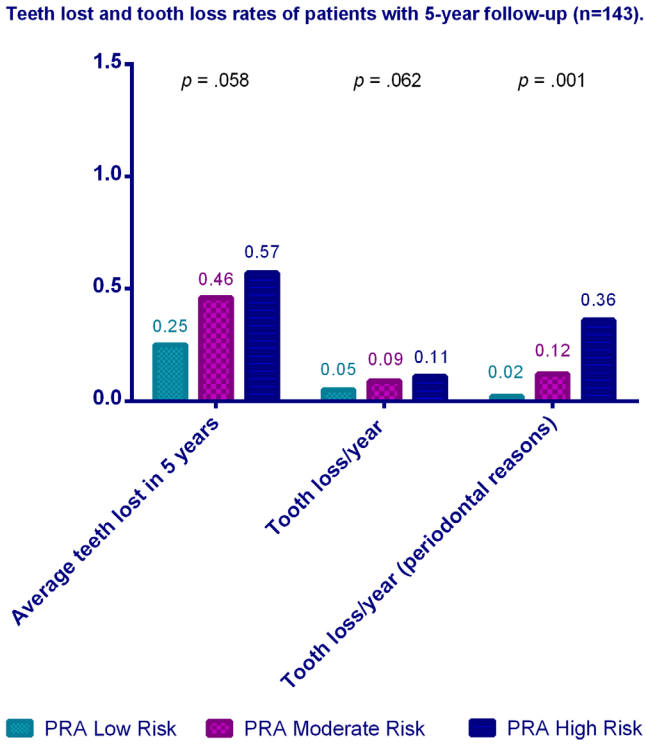

FIGURE 2 Receiver operating characteristic (ROC) curves evaluating the prognostic accuracy for tooth loss for both Tooth Prognosis Score (TPS) and periodontal risk assessment (PRA).

worse score compared with good prognosis, gradually increasing from 'fair' (OR = 3.85, 95% CI = 1.71–8.65, $p = .001$) to 'questionable' (OR = 7.94, 95% CI = 3.13–20, 12, $p = <.001$) and 'unfavourable' (OR = 50.67, 95% CI = 12.60–203.81, $p < .001$). Results from a survival analysis for tooth loss according to the TPS score showed that an unfavourable score was associated with lower tooth survival (Supplemental Material 9). The TPS showed a sensitivity of 76.0%, specificity of 63.0%, positive predictive value of 2.64% and negative predictive value of 99.5% for tooth loss during SPC, and the ROC curve showed an area under the curve of 0.7318 (Figure 2). Table 5 shows an exploratory analysis for tooth loss combining patient risk (PRA) with tooth risk (TPS) and using 'good' prognosis in 'low-risk' patients as reference, considering a multilevel clustering of teeth within patients.

4 | DISCUSSION

Patients prospectively enrolled in SPC in this study lost an average of 0.07 teeth/patient/year, of which less than half were lost for periodontal reasons, showing good stability over 5 years of periodontal maintenance care. Furthermore, just over a third of patients had progression of periodontitis (Tonetti et al., 2005).

This tooth loss rate is very similar to previously reported data in a systematic review (L. Chambrone et al., 2010) and in a 5-year retrospective study including some of the same patients as the present report (Nibali et al., 2017). Trombelli and co-workers reported a mean yearly tooth loss rate of 0.15 and 0.09 during SPC with follow-up of 5 or 12–14 years, respectively (Trombelli et al., 2015), confirming that a maintenance programme based on OHIs and professional plaque control every 4–6 months can effectively minimize tooth loss (Axelsson et al., 2004). A more recent systematic review on 5-year SPC studies (Leow et al., 2022) showed that around 10% of patients experienced tooth loss during this period, which is less than the 24.5% in the present study. It is interesting that no cases of 'extreme downhill' progression (Hirschfeld & Wasserman, 1978) with loss of many teeth during SPC were observed in the present study, suggesting that, while surely extensive genetic predisposition to periodontitis still exists, contemporary methods of plaque control and motivation may prevent extreme tooth loss in most compliant patients, even in the presence of high susceptibility. It is also important to stress that the present sample included a small percentage of smokers and patients with diabetes mellitus. In terms of disease progression, the findings of the present study are in keeping with the current literature (Petsos et al., 2019). Leow and co-workers have recently reported that the incidence of patients experiencing more than one site of CAL loss ≥2 mm over 5 years of SPC was 24.8% (including 86 participants) (Leow et al., 2022), which is lower than 38% in the present study. The higher incidence of patients with progression and tooth loss in the present study compared with the systematic review above may be attributable to initial disease severity and/or to frequency of SPC.

A clear association was detected between the PRA risk profile and both periodontitis progression and tooth loss. This is in agreement with a previous retrospective study from our group (Nibali

TABLE 4 Multilevel logistic regression analysis with outcome tooth loss.

	With 5-year follow-up ($n = 4004$)		All teeth[a] ($n = 4983$)	
	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Location (ant/post)				
Anterior	(Reference)	-	(Reference)	-
Posterior	3.30 (1.65–6.60)	.001	2.92 (1.59–5.37)	.001
Location (Max/Mand)				
Maxillary	(Reference)	-	(Reference)	-
Mandibular	0.73 (0.41–1.31)	.293	0.68 (0.40–1.11)	.157
Deepest PPD	1.92 (1.57–2.35)	<.001	2.05 (1.70–2.47)	<.001
≤3 mm	(Reference)	-	(Reference)	-
4 mm	6.06 (2.65–13.86)	<.001	4.96 (2.31–10.66)	<.001
5 mm	13.03 (5.38–31.55)	<.001	12.06 (5.36–27.11)	<.001
6 mm	21.72 (5.85–80.65)	<.001	15.39 (4.31–54.92)	<.001
≥7 mm	15.22 (3.96–58.50)	<.001	25.15 (7.70–82.12)	<.001
Deepest CAL	1.55 (1.35–1.79)	<.001	1.52 (1.34–1.72)	<.001
Mesial bone loss	1.24 (0.89–1.75)	.206	1.21 (0.87–1.68)	.251
Distal bone loss	3.85 (0.33–45.16)	.283	5.51 (0.61–49.87)	.129
Deepest bone loss	1.20 (0.82–1.75)	.353	1.17 (0.83–1.67)	.372
Restored				
No	(Reference)	-	(Reference)	-
Yes	3.54 (1.71–7.35)	.001	3.83 (1.91–7.66)	<.001
Root canal treatment				
No	(Reference)	-	(Reference)	-
Yes	10.65 (4.70–24.14)	<.001	8.44 (3.94–18.06)	<.001
Bridge/abutment				
No	(Reference)	-	(Reference)	-
Yes	3.14 (0.74–13.33)	.120	2.48 (0.61–10.09)	.205
Periapical lesion				
No	(Reference)	-	(Reference)	-
Yes	11.33 (1.51–85.27)	.018	9.83 (1.45–66.71)	.019
Intrabony defect				
No	(Reference)	-	(Reference)	-
Yes	4.78 (1.81–12.62)	.002	5.18 (2.20–12.22)	<.001
Furcation defect[b]				
No furcation defect	(Reference)	-	(Reference)	-
Class I	1.06 (0.31–3.61)	.926	1.32 (0.44–3.96)	.617
Class II	3.2 (0.89–11.62)	.076	3.84 (1.15–12.87)	.029
Class III	5.65 (1.79–17.83)	.003	5.11 (1.67–15.63)	.004
Mobility				
Degree 0	(Reference)	-	(Reference)	-
Degree 1	1.94 (0.61–6.10)	0.258	1.88 (0.65–5.45)	0.244
Degree 2	88.44 (20.22–386.85)	<.001	59.88 (14.05–255.14)	<.001
Degree 3	-	-	-	-
Tooth Prognosis Score (Nibali et al., 2017)				
Good	(Reference)	-	(Reference)	-
Fair	3.85 (1.71–8.65)	.001	3.04 (1.46–6.34)	.003

(Continues)

TABLE 4 (Continued)

	With 5-year follow-up ($n = 4004$)		All teeth[a] ($n = 4983$)	
	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Questionable	7.94 (3.13–20.12)	<.001	6.75 (2.93–15.57)	<.001
Unfavourable	50.67 (12.60–203.81)	<.001	38.40 (10.32–142.95)	<.001

Note: Odds ratios of several tooth-related variables (tooth-level data). Models accounting for several teeth into each patient. All variables adjusted for age, gender, smoking, diabetes, full mouth plaque score and full mouth bleeding score.
Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Models also adjusted for follow-up time.
[b]Only multi-rooted teeth considered for furcation defect model.

TABLE 5 Multilevel logistic regression analysis (odds ratio [OR]) for tooth loss over 5 years according to Nibali et al.

	Tooth Prognosis Score		
PRA score	Good	Fair	Questionable + unfavourable
Low risk	(Reference)	6.56 (1.86–23.12) $p = .003$	8.15 (1.34–49.66) $p = .023$
Moderate risk	1.70 (0.40–7.14) $p = .469$	6.51 (1.78–23.87) $p = .005$	18.10 (4.63–70.69) $p < .001$
High-risk	4.43 (0.38–51.13) $p = .233$	2.50 (0.23–26.95) $p = .449$	32.35 (6.42–162.98) $p < .001$

Note: Tooth Prognosis Score in each group of PRA risk scores. Each model is presented as OR, 95% CI and *p*-values. Models accounting for several teeth in each patient. All models adjusted for age, gender, smoking, diabetes, full mouth plaque score and full mouth bleeding score.
Abbreviations: CI, confidence interval; PRA, periodontal risk assessment.

et al., 2017) and others (Costa et al., 2012; Eickholz et al., 2008; Leininger et al., 2010; Matuliene et al., 2010). The PRA was also examined in a systematic review (Lang et al., 2015), which included seven retrospective cohort design studies with 648 patients in total, six of which confirmed their association with tooth loss. However, the novelty of this study is its prospective nature, the fact that PRA risk was assigned at baseline and it contributed to tailoring the SPC plan. It is interesting that PRA was associated with tooth loss, even though high-risk patients had a higher frequency of follow-ups, in line with their baseline PRA score. It can be argued that the average difference in SPC frequency throughout the study between PRA low-, moderate- and high-risk patients (8 monthly, 7 monthly and 6monthly) is not enough and that larger differences in frequency (example.g. 12 monthly vs. 6 monthly or 3 monthly) should have been implemented. However, the present study had to face the practicality of a service evaluation in a private practice setting, where patients expressed their views and sometimes missed appointments. Assigning a PRA score can be very important in the aim to personalize treatment, modulate invasiveness of intervention and reduce over-treatment. This was clearly shown in a retrospective study (Giannobile et al., 2013), which suggested that low-risk patients need fewer follow-up visits during SPC compared with high-risk patients. A Cochrane review (Manresa et al., 2018) on randomized controlled trials with a minimum of 12 months follow-up found the quality of evidence to be low or very low and could not make conclusions on the merit of SPC versus monitoring alone/irregular SPC or on optimum frequency of SPC (Manresa et al., 2018). It is not possible to comment on other patient-based risk systems (Saleh et al., 2022), as this study focused specifically on PRA. Both staging and grading showed an association with tooth loss during SPC, approximately four times higher for Stage IV versus III and for Grade C versus B, giving strength to the clinical utility of the current classification (Saleh et al., 2022). It is interesting to notice that, although staging and grading and PRA share some factors, there are also some differences such as definition of former smoking. The question of whether the PRA has a place as a predictive prognostic system remains, as while the negative predictive value was high, the positive predictive value and the area under the curve were low, suggesting a limited ability to predict tooth loss, especially for high-risk patients.

The PRA includes several patient- and tooth-related factors. When looking at the importance of these factors individually, only smoking was associated with tooth loss. A landmark systematic review of longitudinal studies in chronic periodontitis highlighted that age, smoking and initial tooth prognosis were found to be associated with tooth loss (L. Chambrone et al., 2010). The association between smoking and progression and tooth loss is well established (Eickholz et al., 2008; Matuliene et al., 2008; McGuire & Nunn, 1996). In fact, the study was powered to test the effect of smoking on tooth loss, and the hypothesis was proven, with an even larger difference in tooth loss rates than predicted (0.25 teeth vs. 0.65 teeth lost/patient/5 years for non-smokers vs. smokers). BMI was not associated with either tooth loss or disease progression. However, this may be due to reduced power to test the magnitude of this association, rather than to a lack of effect.

Several tooth-based factors showed a statistically significant association with tooth loss during SPC, including PPD, CAL, furcation

involvement, presence of intrabony defects, mobility, previous endodontic treatment, presence of periapical lesions and restoration. These factors are included in the TPS assigned prospectively in this study (Nibali et al., 2017). Not surprisingly, this score was associated with tooth loss. Teeth with 'fair', 'questionable' and 'unfavourable' prognosis had incrementally increasing odds to be lost during the study's follow-up period, confirming the ability of this tooth prognostic system to identify teeth at high risk of tooth loss. We have separately reported, in an analysis focused only on 'highly compliant' patients, how this and other tooth prognosis systems can all accurately identify teeth with a good prognosis, while at the same time struggling to have good predictive value for tooth loss (Saydzai et al., 2022). This was confirmed in the present study, and it may be due to the relatively low frequency of tooth loss, and to the fact that even teeth with 'unfavourable' prognosis can often be maintained in motivated patients in the appropriate setting. In agreement with previous studies (Dopico et al., 2016; Matuliene et al., 2008), increasing PPD at the start of SPC was associated with tooth loss during SPC, reinforcing the concept that residual pockets, especially over the 5-mm threshold (Graziani et al., 2018), represent an incomplete, albeit common, treatment outcome (Sanz et al., 2020). When combining patient- and tooth-risk profiles similar to that attempted in previous studies (Morelli et al., 2017), the combination of high-risk patient and high-risk tooth (questionable/unfavourable) was, as expected, associated with higher chances of tooth loss. However, interestingly, it appeared that tooth prognosis had a stronger influence on tooth loss compared with patient risk in this population. This shows that combining patient- and tooth-related factors may be key to improving the clinician's ability to calculate tooth loss risk.

The main strength of this study is its prospective nature and the fact that tooth- and patient-prognostic systems were assigned at baseline by calibrated examiners, in a field where the majority of SPC studies are retrospective. Furthermore, the study attempted an analysis of a combination of patient- and tooth-related factors in association with tooth loss. A previous systematic review on this topic highlighted that very few adequately sized prospective studies can give evidence to inform maintenance therapy according to individual risk profiles (Lang et al., 2015). This study provides some evidence on this knowledge gap. However, we need to recognize several limitations, due to the large number of patients lost to follow-up (largely due to the COVID-19 pandemic) and the fact that 49% of the patients showed irregular compliance, while we are aware that patients with irregular compliance tend to have a higher risk of tooth loss (Costa et al., 2012; Eickholz et al., 2008; Helal et al., 2019; Ng et al., 2011). No data on nutrition and socio-economic status were available in this study; hence, we could not test their potential effects on periodontal progression and tooth loss. Also, the reported 95% CIs should be interpreted with caution, particularly for certain subgroup analyses, because they are based on a limited sample size, and thus, those intervals are wider. Additionally, this study was conducted in specialized periodontal private practice and the treatment was carried out by a single clinician, thus affecting external validity. The fact that many of the study patients had already been in SPC when the study baseline was carried out is also a limitation, mitigated by adjustment in the analysis. Furthermore, this cohort cannot be considered independent from the patient sample the TPS was validated on, as some of the patients (but at different time points) were also included in the study described by Nibali et al. (2017).

Within the limitations of this study, it can be concluded that low tooth loss rates were detected under strict SPC and that smoking, the patient risk profile (PRA) (Lang & Tonetti, 2003) and a tooth-based TPS (Nibali et al., 2017) were associated with tooth loss, but both showing low positive predictive value for tooth loss. The association with tooth loss was stronger when both were combined. On a patient level, smoking and baseline periodontal staging and grading also seem to increase the risk of tooth loss. Therefore, it is wise to emphasize the importance of using patient-based models to individualize recall visits, in order to personalize care, avoid over-treatment, reduce costs and minimize the recurrence of periodontitis and consequently tooth loss. However, models such as simply staging and grading could have the same use and their predictive abilities should be investigated. The efficacy of patient-based systems in determining different SPC frequency intervals should be tested in randomized controlled trials.

AUTHOR CONTRIBUTIONS

Fatemah Hasan performed data acquisition, prognosis analysis and co-drafted the manuscript. Antonio Magan-Fernandez performed the statistical analysis and co-drafted the manuscript. Aliye Akcalı and Chuanming Sun performed data acquisition. Nikos Donos co-drafted the protocol. Luigi Nibali conceived and supervised the study, co-drafted the protocol and the manuscript, carried out the clinical examinations and performed data interpretation. All authors revised and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study received approval by an ethics committee to be carried out as service evaluation. The study conforms to the Declaration of Helsinki. All participants gave their informed written consent prior to their inclusion in the study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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