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ORIGINAL ARTICLE

Influence of residual pockets on periodontal tooth loss: a retrospective analysis

Muhammad H. A. Saleh[1] | **Debora R. Dias**[2,3] | **Obada Mandil**[1] | **Ricardo P. de Oliveira**[4] | **Abdusalam Alrmali**[1] | **Maurício G. Araújo**[2] | **Hom-Lay Wang**[1] | **Zoltan Barath**[5] | **Istvan A. Urban**[1,5,6,7]

[1]Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA

[2]Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil

[3]Department of Periodontics and Preventive Dentistry, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

[4]Department of Statistics, State University of Maringá, Maringá, Paraná, Brazil

[5]Department of Prosthetic Dentistry, University of Szeged, Szeged, Hungary

[6]Department of Oral Medicine, Infection Control and Immunity, Harvard University, Boston, Massachusetts, USA

[7]Urban Regeneration Institute, Budapest, Hungary

Correspondence
Hom-Lay Wang, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, 1011 North University Avenue, Ann Arbor, Michigan 48109-1078, USA.
Email: homlay@umich.edu

Zoltan Barath and Istvan A. Urban shared senior authorship.

Abstract

Background: Individuals enrolled in supportive periodontal therapy (SPT) can still present with tooth loss due to periodontitis (TLP). There is limited evidence on the influence of residual pockets (RPc) and a defined "threshold" at which a patient's profile is set to be at high risk for TLP in the literature. Therefore, this study aimed to assess the influence of RPc on TLP and determine the prognostic performance of RPc compared to the staging and grading of periodontitis on TLP risk.

Methods: Clinical data from 168 patients (3869 teeth) treated for periodontitis and receiving SPT for at least 10 years were evaluated in this retrospective study. TLP and the percentage of sites with RPc ≥ 5 mm or ≥6 mm per patient were collected. The prognostic performance of RPc was compared to the staging and grading of the disease on TLP using a multilevel Cox proportional hazard regression model.

Results: Over a median follow-up of 25 years, 13.7% of teeth were lost, 4.6% of which were due to periodontitis. Most patients with TLP had ≥1 site with RPc ≥5 mm (90.8%) or ≥6 mm (77.6%). Multivariate multilevel Cox regression revealed that patients with >15% of sites with RPc ≥5 mm had a hazard ratio of 2.34, and grade C had a hazard ratio of 4.6 for TLP compared to RPc ≤4 mm/grade A. Grading exhibited the best discrimination and model fit.

Conclusion: Patients with RPc ≥5 mm at >15% of the sites are at risk for tooth loss. Grading and RPc ≥5 mm displayed very good predictive capability of TLP.

KEYWORDS
periodontal attachment loss, periodontal pocket, periodontitis, tooth loss

1 | INTRODUCTION

In individuals undergoing supportive periodontal therapy (SPT), the incidence of tooth loss (TL) is relatively low, yet it remains an unavoidable eventuality.[1–3] In a retrospective study[4] with 100 patients and 2391 teeth in SPT for 10 years, 5% of the teeth were lost. However, only 1.7% of these were lost due to periodontitis (tooth loss due to periodontitis, TLP). Numerous patient-related (age, sex, smoking, diabetes mellitus, severity of the disease, and compliance with SPT) and tooth-related factors (tooth type, tooth location, probing depth [PD], bleeding on probing [BOP], presence of furcation involvement, mobility, and bone loss) have been suggested to increase the risk of TL or TLP during SPT, including the presence of residual pockets (RPc).[1,4–7]

According to the 2017 World Workshop Classification (WWC), periodontal health in a successfully treated periodontitis patient can be described as PD ≤4 mm at all sites or no PD ≥4 mm with BOP.[8] The European Federation of Periodontology has established the absence of RPc >4 mm with BOP or no deep pockets ≥6 mm as the endpoint of periodontal therapy.[9,10] Nevertheless, clinicians must consider that some patients will not reach this endpoint.[11,12] RPc and BOP are often observed after active periodontal therapy (APT) depending on baseline destruction.[13] At the patient level, previous studies have shown that RPc after APT represents a risk factor for further disease progression.[11,14] In a landmark study, Matuliene et al.[11] assessed the role of RPc (≥5 mm) in predicting TL in 172 patients kept in SPT from 3 to 27 years. The authors observed that during SPT, RPc ≥6 mm was a risk factor for TL at both patient, tooth, and site levels and represented an incomplete periodontal treatment. The study, however, performed the analysis based on TL instead of TLP.

The body of evidence assessing the influence of the frequency of RPc on the risk for TLP is still limited. No defined "threshold" has yet been established at which a patient is classified at high risk for TLP and thus recommended to have more frequent SPT. In addition, several risk assessments like the staging and grading classification have shown a prognostic performance on TL.[15] Although other prognostic systems consider RPc among its categories,[16,17] the predictive performance of RPc as a simple endpoint, stand-alone prognosticator for periodontitis progression has yet to be evaluated. Thus, the aim of this retrospective study was to assess the influence of RPc on TLP in patients in SPT for more than 10 years. As a secondary aim, the prognostic performance of RPc on the risk of TLP was compared to the staging and grading of periodontitis.

2 | MATERIALS AND METHODS

2.1 | Study design and population

This retrospective study assessed clinical data from dental records of patients who received periodontal therapy between January 1966 and January 2008 at the University of Michigan School of Dentistry (SoD), USA. Ethical approval was obtained from the institutional review board of the university (IRBMED; study ID: HUM00157260). Manuscript preparation followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[18]

The inclusion criteria were as follows[19]:

- Individuals diagnosed with periodontitis,[20] who were treated with nonsurgical and, if necessary, surgical therapy and further enrolled in the SPT program for ≥10 years in the university setting.
- Periodontal charts with complete clinical parameters (clinical attachment level [CAL], PD, BOP) and full-mouth periapical radiographs (taken ≤1 year before baseline).
- Patients who received SPT at least once a year during the follow-up period.
- Teeth extracted at the university, with an identifiable reason for extraction in patients' dental records.

The exclusion criteria were the following:

- Smokers who did not report the amount of cigarettes/day.
- Individuals noncompliant to SPT.

2.2 | Active periodontal treatment and maintenance care

All patients received oral hygiene instructions followed by nonsurgical treatment that included supragingival instrumentation and subgingival scaling and root planing. Periodontal surgery was executed if nonsurgical therapy was not sufficient to reach stability.

Following completion of APT, patients were re-evaluated and enrolled in the SPT program at the same institution (baseline examination, T0; first SPT visit). Usually, maintenance visits started with a 3-month interval that was further adapted based on individual factors such as disease severity and longitudinal monitoring. Patients with signs of stability had their maintenance intervals extended up to 1 year. All individuals were kept in SPT for ≥10 years, and data from the last SPT visit (T1) were compared to the baseline data.

2.3 | Variables

The number of sites with RPc ≥ 5 mm or ≥6 mm per patient was collected, transformed into percentages, and individuals were categorized according to it into the following groups: 1%–15% of the sites with RPc, 16%–30% of the sites with RPc, and >30% of the sites with RPc. The incidence of tooth loss due to periodontitis (TLP) was the primary outcome of the present study. Secondary outcomes included the incidence of overall TL, radiographic bone loss (RBL), the influence of staging and grading classification, and other patient- and tooth-level clinical parameters.

2.4 | Data collection

Electronic and physical charts of patients who met the eligibility criteria were screened by two examiners (M.S. and O.M.). At patient level, the following characteristics were collected at T0: age, sex, history of diabetes mellitus (glycosylated hemoglobin [HbA1c] and/or plasma glucose levels), and smoking status. The number of cigarettes/day was stratified into four groups: never smokers; former smokers; light current smokers (<10 cigarettes/day); and heavy current smokers (≥10 cigarettes/day). At T1, the follow-up time and the number of SPT visits were computed.

Clinical and radiographic data were collected at the tooth level at T0 and T1. Third molars were not included in the analysis. Clinical parameters included PD, CAL, and BOP, assessed at six sites/tooth, as well as mobility and furcation involvement.

The presence of vertical bone defects ≥3 mm, any periapical pathology, endodontic root treatment, endodontic post, interproximal restorations, or crowns were determined in the radiographs.

1. Radiographic bone loss (RBL): RBL was determined as the distance 2 mm apical to the cementoenamel junction to the bottom of the bony defect and expressed in percentages, compared to the root length, on periapical radiographs.[19] At molar sites, only the root with the greatest RBL was measured. The worst bone loss (expressed in percentages) at tooth level characterized the patient into favorable (<50%), questionable (≥50% but <70%), or hopeless (≥70%) prognosis.[21]
2. Tooth loss (TL): TL information was classified into TLP and TL. All TL occurring during the follow-up was collected.
3. Residual pockets (RPc): The number of sites (considering six sites/tooth) with RPc ≤4 mm, ≥5 mm, or ≥6 mm per patient was collected and transformed into percentages. Maximum PD per tooth was also considered for the analysis.
4. Staging and grading systems: Individuals were retrospectively classified in accordance with the 2017 WWC[20] into periodontitis stage I, II, III, or IV; localized or generalized (≤30% or >30% of teeth at the most severe stage); and grade A, B, or C by a single investigator (M.S.).

2.5 | Statistical analysis

Mean and standard deviation, as well as median and interquartile range (IQR), were described for continuous variables. Frequency distributions were used for categorical variables. A normality test (Shapiro–Wilk) was performed.

Assuming the percentage of sites with RPc ≥5 mm as the response variable and considering patient-level variables (age, sex, smoking habit, and stage/extent/grade of periodontitis), a linear regression model was used to evaluate which characteristics could increase the number of sites with RPc. A negative binomial model was built to estimate the influence of RPc ≥5 mm and RPc ≥6 mm on TLP at the patient level. A post hoc comparison with the Bonferroni test was performed. The results were reported using estimates or odds ratios and 95% confidence intervals (CI).

The prognostic significance of the percentage of sites with RPc ≥5 mm, RPc ≥6 mm, staging, and grading of periodontitis on TLP was assessed using a multilevel Cox regression frailty model. The analysis was adjusted for the number of SPT visits the tooth underwent throughout the study follow-up. Results were expressed as hazard ratios (HR) including 95% CI. The prognostic performance of the different systems (RPc ≥ 5, RPc ≥ 6, staging and grading) was analyzed regarding its overall performance (Harrell's C-index), model fit (Akaike information criterion [AIC] and Bayesian information criterion [BIC]).

Statistical analyses were computed using dedicated software[*]. The level of significance adopted in the tests was set at 5%.

3 | RESULTS

3.1 | Participants

A total of 168 patients (91 females; 77 males) with a median age of 45 years (37; 54.3) were included in the study. Characteristics of the sample are summarized in Table 1. Individuals presented a median of 27 teeth (25; 28). Most patients had localized stage II or III grade B periodontitis. The time under SPT ranged from 11.5 to 47.8 years (median

[*] JAMOVI statistics (Version 1.6) and R statistical software (R Foundation for Statistical Computing, Vienna, Austria).

TABLE 1 Descriptive data at patient level (A) and tooth level (B).

	Overall	TL	TLP
(A) Patients, *n*	168	130	76
Age, years, median [IQR]	45 [37; 54.3]	45 [36; 55]	44 [36; 53]
Sex, % (*n*)			
Female	54.2 (91)	55.4 (72)	57.9 (44)
Male	45.8 (77)	44.6 (58)	42.1 (32)
Diabetes mellitus, % (*n*)	8.3 (14)	10 (13)	14.5 (11)
Smoking habit, % (*n*)			
Nonsmoker	57.7 (97)	53.8 (70)	46.1 (35)
Former smoker	25 (42)	25.4 (33)	27.6 (21)
≤10 cigarettes/day	8.3 (14)	9.2 (12)	10.5 (8)
≥10 cigarettes/day	8.9 (15)	11.5 (15)	15.8 (12)
Stage of periodontitis, % (*n*)			
Stage I	13.1 (22)	12.3 (16)	9.2 (7)
Stage II	24.4 (41)	21.5 (28)	15.8 (12)
Stage III	51.8 (87)	53.8 (70)	60.5 (46)
Stage IV	10.7 (18)	12.3 (16)	14.5 (11)
Extent of periodontitis, % (*n*)			
Localized	62.5 (105)	62.3 (81)	59.2 (45)
Generalized	37.5 (63)	37.7 (49)	40.8 (31)
Grade of periodontitis, % (*n*)			
Grade A	12.5 (21)	12.3 (16)	10.5 (8)
Grade B	66.7 (112)	61.5 (80)	53.9 (41)
Grade C	20.8(35)	26.2 (34)	35.5 (27)
Maximum bone loss, % (*n*)			
<50%	82.7 (139)	78.5 (102)	75 (57)
≥50% and <70%	9.5 (16)	11.5 (15)	11.8 (9)
≥70%	7.7 (13)	10 (13)	13.2 (10)
RPc, %, mean ± SD, *median [IQR]*			
≥5 mm	10.2 ± 11.8 *5.8 [2; 14.2]*	11.3 ± 11.7 *7.9 [2.4; 16.5]*	13 ± 12.4 *9 [3.4; 18.7]*
≥6 mm	4.9 ± 7.7 *1.8 [0; 5.5]*	5.3 ± 7.8 *2.2 [0.1; 6.2]*	6.4 ± 8.9 *3.7 [0.6; 7.9]*
Follow-up, months, median [IQR]	300 [245; 350]	305 [248; 351]	316 [256; 363]
SPT visits, median [IQR]	57 [43; 71]	57 [43; 71]	61 [48; 71]
(B) Teeth, *n*	3869	531	177
Tooth arch, % (*n*)			
Maxilla	50.7 (1963)	61.8 (328)	59.3 (105)
Mandible	49.3 (1906)	38.2 (203)	40.7 (72)
Tooth region, % (*n*)			
Incisor or canine	42.4 (1639)	21.7 (115)	19.8 (35)
Premolar	29.2 (1129)	27.5 (146)	19.2 (34)
Molar	28.5 (1101)	50.8 (270)	61 (108)
Clinical parameters (T0)			
PD (mm), median [IQR]	4 [3; 5] ($n = 3846$)	5 [4; 6] ($n = 518$)	5 [4; 6] ($n = 174$)
RPc ≥ 5 (yes/no)	1169/2677	282/219	115/59
RPc ≥ 6 (yes/no)	584/3262	156/362	65/109

(Continues)

TABLE 1 (Continued)

	Overall	TL	TLP
CAL (mm)	3 [2; 4] (n = 3158)	4 [3; 5] (n = 428)	5 [3; 6] (n = 150)
BOP (yes/no)	599/1267	66/105	26/36
RBL (%)	(n = 3661)	(n = 512)	(n = 173)
<15%	53.3	39.1	24.3
15%–33%	32.1	38.1	45.7
>33%	14.5	22.9	30
Furcation involvement, % (n)	(n = 1113)	(n = 280)	(n = 110)
Grade I	19.9 (221)	21.1 (59)	25.5 (28)
Grade II	8.7 (97)	13.6 (38)	19.1 (21)
Grade III	1 (11)	2.1 (6)	1.8 (2)
Mobility, % (n)	(n = 3863)		
Class I	12.9 (500)	20.3 (108)	26.6 (47)
Class II	1.4 (54)	4.3 (23)	6.8 (12)
Class III	0.3 (10)	0.8 (4)	1.1 (2)
Interproximal restoration (yes/no)	735/2955	137/388	44/131
Crown (yes/no)	487/3203	118/406	41/134
Retainer (yes/no)	51/3640	11/514	3/173
Apical pathology (yes/no)	22/3669	6/519	1/175
RCT (yes/no)	149/3542	43/482	14/162
Endodontic post (yes/no)	62/3629	20/505	4/172
Vertical defect >3 mm (yes/no)	90/3601	27/498	12/164

Abbreviations: BOP, bleeding on probing; CAL, clinical attachment level; IQR, interquartile range; PD, probing depth; RBL, radiographic bone loss; RPc, residual pocket; RCT, root canal treatment; SD, standard deviation; SPT, supportive periodontal therapy; T0, baseline examination; TL, tooth loss; TLP, tooth loss due to periodontitis.

25.1 years [20.4; 29.2]), and the number of visits ranged from 16 to 101 (median 57 [45.8; 72.3]). At baseline, 3869 teeth were included, of which 50.7% were in the maxilla and 49.3% in the mandible. Clinical parameters at T0 and T1 are available in Supplementary Table S1 in the online *Journal of Periodontology*.

3.2 | TL due to periodontitis

Over 25 years of follow-up, 531 teeth (13.7%) were lost; 177 (4.6%) of which were due to periodontitis, resulting in a mean loss rate of 0.13 (min 0, max 1.22) and 0.04 (min 0, max 0.62) teeth/patient/year, respectively. At patient level, 77.4% of the patients experienced TL, while 45.2% experienced TLP (Figure 1A).

3.3 | Residual pockets

At T0, patients had a median of 5.8% (2; 14.2) of the sites with RPc ≥ 5 mm and 1.8% (0; 5.5) of the sites with RPc ≥ 6 mm (Table 1a). The frequency distribution showed that approximately 11% of the patients did not have any sites with RPc ≥ 5 mm (Figure 1B, C), while the majority of patients had RPc ≥ 5 mm in 1%–15% of their sites (66.1%). Similarly, most patients had 1%–15% of the sites with RPc ≥ 6 mm (61.9%).

At tooth level, 30.4% of the teeth had RPc ≥ 5 mm and 15.2% had RPc ≥ 6 mm. After an average follow-up of 25 years, the percentages of teeth with RPc ≥ 5 and ≥6 mm decreased to 11.2% and 3.7%, respectively (see Supplementary Table S1 in online *Journal of Periodontology*).

3.3.1 | Linear regression model

A linear regression model assessed the patient-level predictors for increasing sites with RPc ≥ 5 mm. The staging and extension of periodontitis, as well as sex (males), were identified as predictors for a higher percentage of sites with RPc (see Supplementary Table S2 in online *Journal of Periodontology*).

3.4 | RPc and TLP

Most patients who experienced TLP had RPc ≥ 5 mm (90.8%) or ≥6 mm (77.6%). The higher the

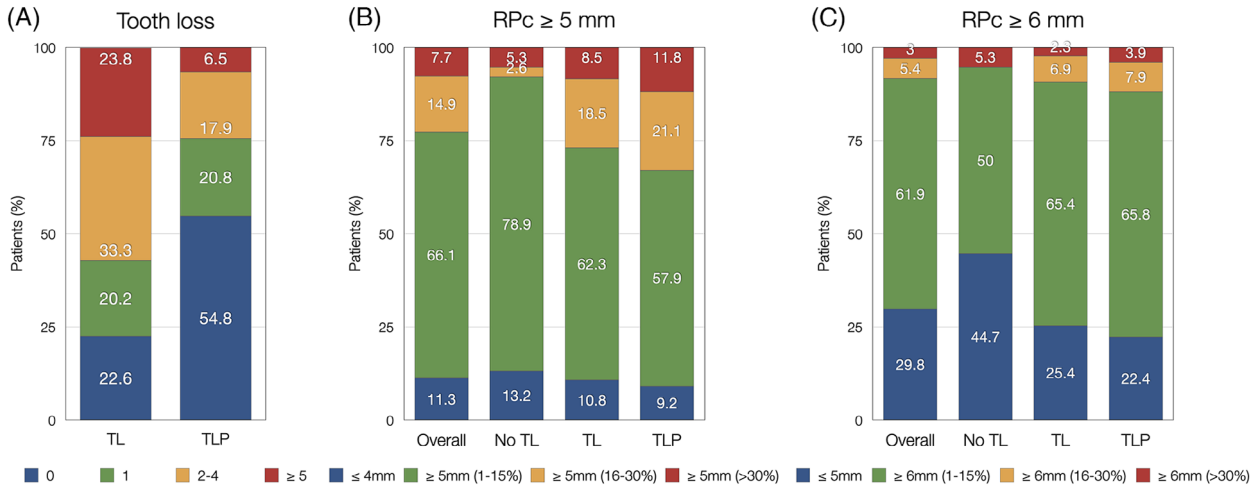

FIGURE 1 Frequency distribution of (A) percentage of teeth lost per patient in general (TL) and due to periodontitis (TLP). Percentage of sites per patient with residual pockets (RPc) ≥ 5 mm (B) or RPc ≥ 6 mm (C) in overall sample, in patients without tooth loss (no TL), in patients with general tooth loss (TL), and patients with tooth loss due to periodontitis (TLP).

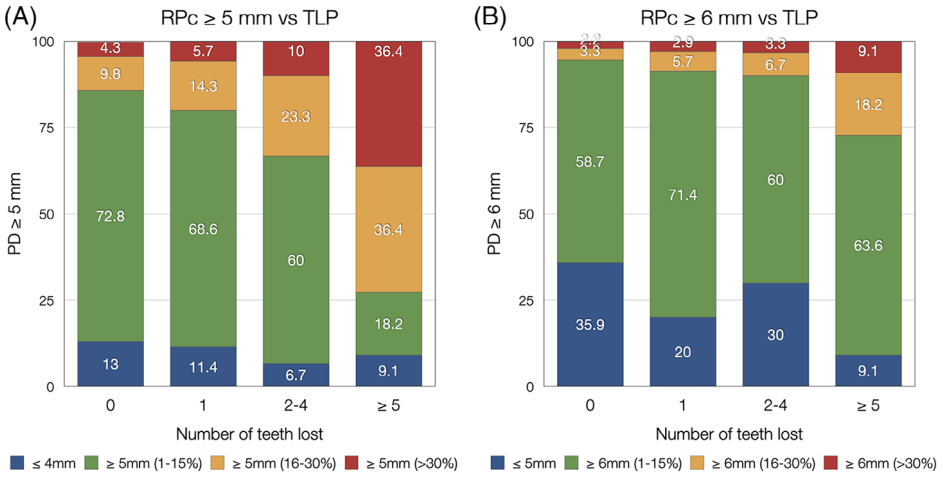

FIGURE 2 Frequency distribution of sites with residual pockets (RPc) ≥ 5 mm (A) and ≥6 mm (B) according to number of teeth lost. PD, probing depth; TLP, tooth loss due to periodontitis.

percentage of sites with RPc, the higher the incidence of TL (Figure 2A, B).

3.4.1 | Negative binomial model

The results of the negative binomial model that assessed the influence of RPc (≥5 mm and ≥6 mm) on the number of teeth lost due to periodontitis (patient level) are presented in Table 2 and Figure 3A, B. Considering RPc ≥ 5 mm, the expected number of TLP increased by 2.69 times (95% CI, 1.11–6.67; $p = 0.03$) when 16%–30% of the sites had RPc and 4.5 times (95% CI, 1.66–12.12; $p = 0.003$) when >30% of the sites were affected. In addition, patients with up to 15% of the sites with RPc were not at higher risk for TL. Post hoc comparison with the Bonferroni test (see Supplementary Table S3 in online *Journal of Periodontology*) revealed that the odds ratio increased across different risk class categories. Significant differences were observed between patients with no sites with RPc ≥ 5 mm (≤4-mm category) and those with >30% of the sites with RPc ≥ 5 mm (Bonferroni $p = 0.02$). Additionally, significant differences were found between patients with 1%–15% of the sites with RPc ≥ 5 mm and those with >30% of the sites with RPc ≥ 5 mm (Bonferroni $p = < 0.001$), as well as between patients with 1%–15% of the sites with RPc ≥ 5 mm and those with 16%–30% of the sites with RPc ≥ 5 mm (Bonferroni $p = 0.01$).

For RPc ≥ 6 mm, the odds ratio was increased across the different risk class parameters (Table 2). The expected number of teeth lost due to periodontitis increased by 4.85 times (95% CI, 1.51–20.40; $p = 0.015$) when >30% of

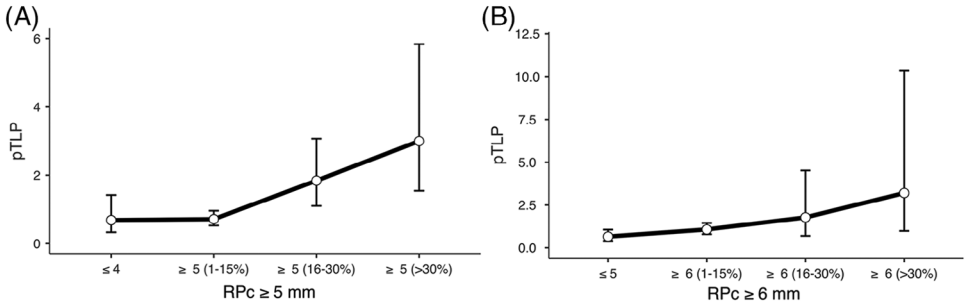

FIGURE 3 Predicted plots of patients' tooth loss due to periodontitis according to percentage of sites with residual pockets (RPc) ≥ 5 mm (A) or ≥6 mm (B). pTLP, percentage of tooth loss due to periodontitis.

TABLE 2 Negative binomial model to assess influence of residual pockets (RPc) ≥ 5 mm or RPc ≥ 6 mm on number of teeth lost per patient due to periodontitis.

RPc ≥ 5mm			
Predictor	**Odds ratio**	**95% CI**	***p* value**
Intercept	1.28	0.96–1.71	0.092
PD ≥ 5 mm (%)			
≥5 mm (1%–15%) – ≤4 mm	1.04	0.47–2.32	0.922
≥5 mm (16%–30%) – ≤4 mm	2.69	1.11–6.67	0.030*
≥5 mm (>30%) – ≤4 mm	4.38	1.66–12.12	0.003*
RPc ≥ 6mm			
Predictor	**Odds ratio**	**95% CI**	***p* value**
Intercept	1.42	0.97–2.19	0.087
PD ≥ 6 mm (%)			
≥6 mm (1%–15%) – ≤5 mm	1.63	0.93–2.88	0.089
≥6 mm (16%–30%) – ≤5 mm	2.69	0.98–8.23	0.064
≥6 mm (>30%) – ≤5 mm	4.85	1.51–20.40	0.015*

Abbreviation: PD, probing depth.
*Statistically significant.

the sites had RPc. No statistically significant differences were observed in the multiple comparisons (Bonferroni $p \geq 0.05$; see Supplementary Table S3 in online *Journal of Periodontology*).

3.5 | Survival analysis

The prognostic significance of RPc ≥ 5 mm, RPc ≥ 6 mm, and staging and grading systems of periodontitis to predict TLP were assessed using a multilevel Cox regression frailty model (Table 3a) with univariate and multivariate analysis. After adjusting for the number of SPT visits, the results were used as a final reference to determine the prognostic significance of different variables on TLP. For the presence of RPc ≥ 5 mm, the HR increased among the different risk class categories. When 16%–30% of the sites had RPc ≥ 5 mm, the HR of TLP was 2.34 (95% CI, 0.99–5.4; $p = 0.05$) compared to sites with RPc ≤4 mm. For the presence of RPc ≥ 6 mm, the HR increased among the different risk class categories. When >30% of the sites had RPc ≥ 6 mm, the hazard ratio of TL was 2.98 (95% CI, 0.84–10.57; $p = 0.09$) compared to sites with RPc ≤5 mm. Although statistically significant in the univariate analysis, with increasing hazard ratios, the staging of periodontitis showed no statistically significant prognostic performance in the multivariate analysis. Grade C presented an HR for TLP of 4.62 (95% CI, 2.19–9.74; $p < 0.001$).

3.5.1 | Model performance

The prognostic performance of the different systems was assessed. The grading system showed the best performance concerning discrimination (Harrell's C = 0.696) and model fit (AIC = 2566 and BIC = 2671), although the values for all systems were very similar (Table 3b).

4 | DISCUSSION

This retrospective study aimed to assess the influence of RPc on TLP in patients in SPT for 10 years or more. Our results demonstrated that sites with RPc ≥ 5 mm or ≥6 mm following APT increased the risk of patient-level periodontitis progression as assessed via TLP. RPc were as predictive as the grading of periodontitis, particularly when a higher percentage of sites were affected.

On average, the rates of TL and TLP over 25 years were 13.7% (0.13 teeth/patient/year) and 4.6% (0.04 teeth/patient/year), respectively. The annual TL per patient is in line with previous studies on TL[3,4,22] and TLP.[4,22,23] Similarly, a recent systematic review,[1] which included 33 prospective and retrospective studies with at least 5 years in SPT, reported an average TL of 0.1–0.2 teeth/patient/year. In addition, 16 studies reported data on TLP, resulting in 53,995 teeth, of which 2,720

TABLE 3 Univariate and multivariate risk stratification performed for periodontal-related tooth loss using multilevel Cox regression frailty models (A). Comparison of model risk stratification performance using measurements of model fit (Akaike information criterion and Bayesian information criterion) and prognostic discrimination (Harrell's C-index) (B).

(A) Variables		Multilevel univariate analysis		Multilevel multivariate analysis	
		HR (95% CI)	*p* value	HR (95% CI)	*p* value
RPc ≥ 5	≤4 (Ref)	–	–	–	–
	≥5 (1%–15% sites)	1.09 (0.60–1.96)	0.78	1.35 (0.65–2.79)	0.42
	≥5 (16%–30% sites)	2.30 (1.24–4.28)	0.009*	2.34 (0.99–5.47)	0.05
	≥5 (>30% sites)	3.15 (1.66–5.96)	<0.001*	2.32 (0.79–6.76)	0.12
RPc ≥ 6	≤5 (Ref)	–	–	–	–
	≥6 (1%–15% sites)	1.56 (1.06–2.32)	0.025*	0.46 (0.26–0.82)	0.009*
	≥6 (16%–30% sites)	1.98 (1.08–3.63)	0.026*	0.84 (0.28–2.48)	0.75
	≥6 (>30% sites)	3.01 (1.64–5.525)	<0.001*	2.98 (0.84–10.57)	0.09
Staging	1 (Ref)	–	–	–	–
	2	1.44 (0.67–3.09)	0.35	0.68 (0.31–1.51)	0.35
	3	2.58 (1.30–5.11)	0.006*	1.63 (0.77–3.45)	0.20
	4	4.26 (2.03–8.91)	<0.001*	0.79 (0.30–2.07)	0.64
Grading	A (Ref)	–	–	–	–
	B	1.22 (0.65–2.31)	0.54	0.79 (0.39–1.59)	0.51
	C	3.79 (2.01–7.12)	<0.001*	4.62 (2.19–9.74)	<0.001*
Maintenance		0.89 (0.88–0.90)	<0.001*	0.88 (0.87–0.89)	<0.001*

(B)	Multilevel univariate analysis			Multilevel multivariate analysis		
	Harrell's C-index	Akaike information criterion	Bayesian information criterion	Harrell's C-index	Akaike information criterion	Bayesian information criterion
RPc ≥ 5	0.631	2618	2702	0.641	2608	2682
RPc ≥ 6	0.588	2638	2722	0.635	2590	2682
Staging	0.609	2603	2709	0.649	2584	2685
Grading	0.646	2125	2679	0.696	2566	2671

Note: The higher Harrell's C-index and the lower the Akaike information criterion and the Bayesian information criterion, the better the performance of the prognostic model.

Abbreviations: HR, hazard ratio; RPc ≥ 5, percentage of sites with residual pockets of 5 mm or more; RPc ≥ 6, percentage of sites with residual pockets of 6 mm or more.

*Statistically significant.

(5.04%; ranging from 0.45% to 14.4%) were lost due to periodontal reasons. On the other hand, even though Siow et al.[6] reported that 5.6% of teeth were lost during SPT and 3.6% due to periodontitis over an average of 6 years in SPT, a higher incidence of TLP during periodontal maintenance was observed, namely 0.14 teeth/patient/year. The contrary was observed by Agudio et al.[24] over 30 years of follow-up. Overall, 201 (5.1%) teeth were extracted during SPT, resulting in a total loss of 0.04 teeth/patient/year, of which only 39 (1%) were due to periodontal reasons, that is, 0.01 teeth/patient/year. These discrepancies could be further explained due to different follow-ups, characteristics of the population, and treatment/SPT approaches.[25] Besides, in the present study, 77.4% of the patients lost at least one tooth, while 45.2% were due to periodontal reasons. These findings are in agreement with previous studies, suggesting that TL is a consequence of periodontal disease that is occasionally observed and must be prevented.[6,26]

RPc are commonly observed after APT.[27–29] In the present study, about 89% of the individuals had at least one site with RPc ≥ 5 mm and 70% with RPc ≥ 6 mm. Nevertheless, most patients had RPc in only 1%–15% of the sites (66% and 62%, respectively), resulting in a median of 5.8% of the sites (mean 10.2%) with RPc ≥ 5 mm and 1.8% of the sites (mean 4.9%) with RPc ≥ 6 mm. These values are in agreement with a recent systematic review[13] that evaluated the efficacy of nonsurgical therapy on RPc. A meta-analysis was performed based on six studies, resulting in a mean percentage of 11.71% (95% CI, 7.88–15.54) RPc ≥ 5 mm after treatment. Another systematic review[30] that evaluated the effect of periodontal regeneration approaches for intrabony defects, observed that pocket closure (PD ≤4 mm) was observed in a weighted mean percentage of 92.1% of

the sites. Therefore, no matter the treatment approach, RPc are often observed following APT. Our study's linear regression analysis showed that a higher percentage of sites with RPc were associated with the staging and extent of periodontitis and sex (males). These findings suggest that the percentage of sites with RPc is associated with the severity of the disease, which was also previously reported by other authors.[31,32] As expected, the prevalence of RPc decreased over time in SPT, and at the end of the study, only 11.2% and 3.7% of the teeth presented RPc ≥ 5 and ≥6 mm, respectively. This reduction can be explained because the most severely affected teeth were either lost or presented gingival recessions.

In the current study, the presence of RPc was directly associated to TLP. In patients that presented RPc ≥ 5 mm, the expected number of TLP increased by 2.69 times when 16%–30% of the sites were involved and 4.5 times when >30% of the sites were affected. This information may aid clinicians in identifying patients at an increased risk for TLP and tailoring their treatment plans accordingly. These findings are in agreement with previous studies that evaluated the association of sites with RPc and TL or periodontitis progression.[11,14,33–38] Matuliene et al.[11] observed that the presence of ≥9 sites with RPc ≥ 5 mm was associated with periodontitis progression but not with TL, while Siow et al.[6] observed that RPc ≥ 5 mm at ≥5 sites were considered a significant risk factor for TLP over SPT (incidence rate ratio = 2.04). However, our study advances the understanding of the influence of the frequency of RPc on the risk of TLP, suggesting that a higher percentage of affected sites further increases this risk. Furthermore, previous studies have indicated that when RPc ≥ 5 mm is associated with persisting BOP, it has a positive predictive factor for further disease progression during SPT.[7,8,11,14,31] One of the major limitations of the present study is that the association between RPc and BOP was not evaluated; however, it could be suggested that deep pockets have a higher tendency for bleeding due to a wider area of junctional epithelium and altered complexity of the subgingival biofilm.[12,28,39–43] In fact, in Tonetti et al.'s[31] study, more than one out of two sites with PD ≥ 4 mm were positive for BOP. Besides, one of the endpoints suggested by the European Federation of Periodontology is the absence of deep pockets ≥6 mm, without considering BOP, based on the assumption that these sites will be at risk for disease progression.[9,10] Therefore, persistent deep pockets that are associated with stage III or IV or more severe grading may harbor more pathogenic bacteria, potentially increasing the risk for the progression of periodontitis and TLP. Consequently, they may require further treatment.

On the other hand, individuals with ≤15% of the sites with RPc ≥ 5 mm had very low risk of TLP, suggesting that patients with very few sites with RPc still can be considered properly treated. These findings are in agreement with Feres et al.,[44] who suggested that for patients treated for periodontitis, a clinical endpoint of "≤4 sites with PD ≥ 5 mm" could be valid to determine disease remission/control after APT. In accordance with these outcomes, the concept of a stable periodontitis patient status was recently introduced with the new classification.[8] The status of periodontal stability can be defined as the combination of successful treatment and controlling of local and systemic risk factors, resulting in PD ≤4 mm, no sites with PD ≥ 4 mm + BOP, and full-mouth bleeding scores <10%. Bertl et al.[32] assessed the effects of attaining a successfully treated stable periodontitis patient status in the long term. One-hundred periodontitis patients kept in SPT were evaluated. At the end of APT, only 21% of the patients were included in the successfully treated stable status. Most patients were not classified as stable due to one to four diseased teeth, while 15% of the patients presented ≥5 diseased teeth. A multivariate analysis showed that an unstable status, an increased number of diseased teeth/patient at the first SPT, and suboptimal oral hygiene standards significantly increased the risks for an increased number of diseased teeth/patient and TLP.[32] In contrast, patients who were highly adherent to SPT seemed to reduce the negative effect of an unstable status, particularly regarding TLP. Thus, it can be suggested that very few RPc in patients under a strict SPT program may not need further treatment.

Comparing the prognostic performance of RPc with the staging and grading of periodontitis, we found that RPc were a significant predictor of TLP. Although the staging and grading classification has prognostic value for TL,[15,45] our study emphasizes the clinical relevance of RPc as an additional factor to be considered in risk assessment and treatment planning. Saleh et al[15] compared the prognostic performance of four periodontal risk assessment tools on TLP. Two of them were based on pretreatment clinical variables to predict the risk for TLP, the staging and grading, and the periodontal risk calculator, while the two others used posttreatment variables retrieved at the reevaluation appointment, the Periodontal Risk Assessment and PerioRisk. The authors reported that the PerioRisk tool exhibited the best discrimination and model fit to predict TLP, and the Periodontal Risk Assessment ranked second. Interestingly, these two periodontal risk assessment tools have RPc as a parameter. Another study[46] addressed the limitations of assessing the prognosis based on baseline data. The authors suggest that it may be very interesting for treatment planning, however, over a period of 10 years, a tooth prognosis may change. Therefore, staging and grading is a predictable tool, but for long-term (≥5 years) prognosis, a tool that accepts constant changes

would enhance the communication between the clinician and patient. Another study[47] that compared different tooth prognosis systems suggested that the employment of more accurate yet less complicated systems, which incorporate patient and tooth factors, might be suitable in the future, especially considering the advances in the use of artificial intelligence.

Our findings should be understood in the context of limitations. First, the retrospective design and reliance on electronic and physical charts may have introduced information bias. Second, the study population was limited to patients treated at the University of Michigan SoD by dental students and residents, which may potentially reduce the generalizability of the results because the examiners were not experienced. Third, nonsurgical and surgical treatment of periodontitis were combined, and thus no conclusions could be drawn. However, the longitudinal nature of the study and the large sample size with a diverse range of patient and tooth characteristics strengthen our conclusions. Besides, the decision for tooth extraction may vary between clinicians, depending on their experience, clinical decision, and patients' considerations. Nevertheless, teeth lost due to nonperiodontal reasons were not included in the regression analyses, so the findings of this investigation are specific for TLP. The absence of a priori sample size calculation is another limitation since the available sample size was predetermined. Our strict inclusion criteria and complete case analysis may have certainly resulted in some sort of inclusion bias. We faced a statistical distribution where the bulk of patients are clustered in stages II and III, with smaller numbers extending into stages I and IV, creating a typical bell curve distribution that could underpower the sample size for stages I and IV. However, this distribution seems to be typical of the periodontitis distribution in the general population. Finally, it was not assessed whether the teeth extracted during APT and SPT were replaced by tooth-supported bridges, removable dentures, or implants or not. This could have an impact on the long-term outcomes since occlusion plays a major role in the stability of the dentition of periodontitis patients.[20] One crucial aspect to be considered is that the percentage of sites with RPc in our study was established considering the assessment of six sites per tooth; therefore, the extrapolation of these findings to four sites per tooth must be carefully evaluated.

5 | CONCLUSION

In conclusion, this study highlights that the presence of RPc following APT is a significant risk factor for TL in patients undergoing SPT. Individuals with >15% of the sites exhibiting RPc ≥ 5 mm had increased hazard ratios of TL. Conversely, patients with ≤15% sites with RPc ≥ 5 mm showed a similar risk of TL as those with RPc ≤4 mm. This suggests that up to 15% of the sites could be considered as a clinical endpoint in monitoring RPc. Our findings emphasize the importance of addressing RPc during SPT to prevent TL. Moreover, in addition to considering the staging and grading of periodontitis, RPc should be considered in risk assessment and treatment planning. Furthermore, the significance of BOP in the accurate assessment of periodontal health and timely prevention of periodontal disease progression during SPT should not be underestimated. Future prospective studies are warranted to explore the association between RPc and TLP along with BOP, as well as to investigate the potential benefits of different SPT approaches in reducing the risk of TL in patients with RPc.

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ORCID

Muhammad H. A. Saleh https://orcid.org/0000-0001-5067-7317
Debora R. Dias https://orcid.org/0000-0002-5387-1753
Obada Mandil https://orcid.org/0000-0001-6797-7949
Abdusalam Alrmali https://orcid.org/0000-0001-7437-6279
Maurício G. Araújo https://orcid.org/0000-0003-2224-982X
Hom-Lay Wang https://orcid.org/0000-0003-4238-1799

REFERENCES

1. Carvalho R, Botelho J, Machado V, et al. Predictors of tooth loss during long-term periodontal maintenance: an updated systematic review. *J Clin Periodontol*. 2021;48(8):1019-1036.
2. Eickholz P, Kaltschmitt J, Berbig J, Reitmeir P, Pretzl B. Tooth loss after active periodontal therapy. 1: patient-related factors for risk, prognosis, and quality of outcome. *J Clin Periodontol*. 2008;35(2):165-174.
3. Pretzl B, El Sayed S, Weber D, Eickholz P, Bäumer A. Tooth loss in periodontally compromised patients: results 20 years after active periodontal therapy. *J Clin Periodontol*. 2018;45(11):1356-1364.
4. Petsos H, Schacher B, Ramich T, et al. Retrospectively analysed tooth loss in periodontally compromised patients: long-term results 10 years after active periodontal therapy-Patient-related outcomes. *J Periodontal Res*. 2020;55(6):946-958.
5. Helal O, Göstemeyer G, Krois J, et al. Predictors for tooth loss in periodontitis patients: systematic review and meta-analysis. *J Clin Periodontol*. 2019;46(7):699-712.
6. Siow DSF, Goh EXJ, Ong MMA, Preshaw PM. Risk factors for tooth loss and progression of periodontitis in patients undergoing periodontal maintenance therapy. *J Clin Periodontol*. 2023;50(1):61-70.

7. Ramseier CA, Nydegger M, Walter C, et al. Time between recall visits and residual probing depths predict long-term stability in patients enrolled in supportive periodontal therapy. *J Clin Periodontol*. 2019;46(2):218-230.
8. Chapple ILC, Mealey BL, Van Dyke TE, et al. Periodontal health and gingival diseases and conditions on an intact and a reduced periodontium: consensus report of workgroup 1 of the 2017 World Workshop on the classification of periodontal and peri-implant diseases and conditions. *J Periodontol*. 2018;89:S74-84.
9. Sanz M, Herrera D, Kebschull M, et al. Treatment of stage I-III periodontitis-The EFP S3 level clinical practice guideline. *J Clin Periodontol*. 2020;47(22):4-60.
10. Herrera D, Sanz M, Kebschull M, et al. Treatment of stage IV periodontitis: the EFP S3 level clinical practice guideline. *J Clin Periodontol*. 2022;49(24):4-71.
11. Matuliene G, Pjetursson BE, Salvi GE, et al. Influence of residual pockets on progression of periodontitis and tooth loss: results after 11 years of maintenance. *J Clin Periodontol*. 2008;35(8):685-695.
12. Loos BG, Needleman I. Endpoints of active periodontal therapy. *J Clin Periodontol*. 2020;47(22):61-71.
13. Citterio F, Gualini G, Chang M, et al. Pocket closure and residual pockets after non-surgical periodontal therapy: a systematic review and meta-analysis. *J Clin Periodontol*. 2022;49(1):2-14.
14. Claffey N, Egelberg J. Clinical indicators of probing attachment loss following initial periodontal treatment in advanced periodontitis patients. *J Clin Periodontol*. 1995;22(9):690-696.
15. Saleh MHA, Dukka H, Troiano G, et al. Long term comparison of the prognostic performance of PerioRisk, periodontal risk assessment, periodontal risk calculator, and staging and grading systems. *J Periodontol*. 2022;93(1):57-68.
16. Lang NP, Tonetti MS. Periodontal risk assessment (PRA) for patients in supportive periodontal therapy (SPT). *Oral Health Prev Dent*. 2003;1(1):7-16.
17. Trombelli L, Farina R, Ferrari S, Pasetti P, Calura G. Comparison between two methods for periodontal risk assessment. *Minerva Stomatol*. 2009;58(6):277-287.
18. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol*. 2008;61(4):344-349.
19. Saleh MHA, Dukka H, Troiano G, et al. External validation and comparison of the predictive performance of 10 different tooth-level prognostic systems. *J Clin Periodontol*. 2021;48(11):1421-1429.
20. Papapanou PN, Sanz M, Buduneli N, et al. Periodontitis: consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Periodontol*. 2018;89(S1):S173-182.
21. Graetz C, Dörfer CE, Kahl M, et al. Retention of questionable and hopeless teeth in compliant patients treated for aggressive periodontitis. *J Clin Periodontol*. 2011;38(8):707-714.
22. Petsos H, Ramich T, Nickles K, et al. Tooth loss in periodontally compromised patients: retrospective long-term results 10 years after active periodontal therapy – tooth-related outcomes. *J Periodontol*. 2021;92(12):1761-1775.
23. Martinez-Canut P. Predictors of tooth loss due to periodontal disease in patients following long-term periodontal maintenance. *J Clin Periodontol*. 2015;42(12):1115-1125.
24. Agudio G, Buti J, Bonaccini D, Pini Prato G, Cortellini P. Longevity of teeth in patients susceptible to periodontitis: clinical outcomes and risk factors associated with tooth loss after active therapy and 30 years of supportive periodontal care. *J Clin Periodontol*. 2023;50(4):520-532.
25. Ravidà A, Galli M, Saleh MHA, et al. Maintenance visit regularity has a different impact on periodontitis-related tooth loss depending on patient staging and grading. *J Clin Periodontol*. 2021;48(8):1008-1018.
26. Rosling B, Serino G, Hellström MK, Socransky SS, Lindhe J. Longitudinal periodontal tissue alterations during supportive therapy. Findings from subjects with normal and high susceptibility to periodontal disease. *J Clin Periodontol*. 2001;28(3):241-249.
27. Sanz-Sánchez I, Montero E, Citterio F, Romano F, Molina A, Aimetti M. Efficacy of access flap procedures compared to subgingival debridement in the treatment of periodontitis. A systematic review and meta-analysis. *J Clin Periodontol*. 2020;47(S22):282-302.
28. Graziani F, Karapetsa D, Mardas N, Leow N, Donos N. Surgical treatment of the residual periodontal pocket. *Periodontol 2000*. 2018;76(1):150-163.
29. Graziani F, Karapetsa D, Alonso B, Herrera D. Nonsurgical and surgical treatment of periodontitis: How many options for one disease? *Periodontol 2000*. 2017;75(1):152-188.
30. Aimetti M, Fratini A, Manavella V, et al. Pocket resolution in regenerative treatment of intrabony defects with papilla preservation techniques: a systematic review and meta-analysis of randomized clinical trials. *J Clin Periodontol*. 2021;48(6):843-858.
31. Tonetti MS, Muller-Campanile V, Lang NP. Changes in the prevalence of residual pockets and tooth loss in treated periodontal patients during a supportive maintenance care program. *J Clin Periodontol*. 1998;25(12):1008-1016.
32. Bertl K, Pandis N, Stopfer N, Haririan H, Bruckmann C, Stavropoulos A. The impact of a "successfully treated stable periodontitis patient status" on patient-related outcome parameters during long-term supportive periodontal care. *J Clin Periodontol*. 2022;49(2):101-110.
33. Ravald N, Johansson CS. Tooth loss in periodontally treated patients: a long-term study of periodontal disease and root caries. *J Clin Periodontol*. 2012;39(1):73-79.
34. Graetz C, Schützhold S, Plaumann A, et al. Prognostic factors for the loss of molars–an 18-years retrospective cohort study. *J Clin Periodontol*. 2015;42(10):943-950.
35. Graetz C, Sälzer S, Plaumann A, et al. Tooth loss in generalized aggressive periodontitis: prognostic factors after 17 years of supportive periodontal treatment. *J Clin Periodontol*. 2017;44(6):612-619.
36. Saminsky M, Halperin-Sternfeld M, Machtei EE, Horwitz J. Variables affecting tooth survival and changes in probing depth: a long-term follow-up of periodontitis patients. *J Clin Periodontol*. 2015;42(6):513-519.
37. Renvert S, Persson GR. A systematic review on the use of residual probing depth, bleeding on probing and furcation status following initial periodontal therapy to predict further attachment and tooth loss. *J Clin Periodontol*. 2002;29(S3):82-89.

38. Salvi GE, Mischler DC, Schmidlin K, et al. Risk factors associated with the longevity of multi-rooted teeth. Long-term outcomes after active and supportive periodontal therapy. *J Clin Periodontol*. 2014;41(7):701-707.
39. Lang NP, Joss A, Orsanic T, Gusberti FA, Siegrist BE. Bleeding on probing. A predictor for the progression of periodontal disease? *J Clin Periodontol*. 1986;13(6):590-596.
40. Joss A, Adler R, Lang NP. Bleeding on probing. A parameter for monitoring periodontal conditions in clinical practice. *J Clin Periodontol*. 1994;21(6):402-408.
41. Zhuang LF, Watt RM, Steiner S, et al. Subgingival microbiota of Sri Lankan tea labourers naïve to oral hygiene measures. *J Clin Periodontol*. 2014;41(5):433-441.
42. Mombelli A, Nyman S, Brägger U, Wennström J, Lang NP. Clinical and microbiological changes associated with an altered subgingival environment induced by periodontal pocket reduction. *J Clin Periodontol*. 1995;22(10):780-787.
43. Mombelli A. Microbial colonization of the periodontal pocket and its significance for periodontal therapy. *Periodontol 2000*. 2018;76(1):85-96.
44. Feres M, Retamal-Valdes B, Faveri M, et al. Proposal of a clinical endpoint for periodontal trials: the treat-to-target approach. *J Int Acad Periodontol*. 2020;22(2):41-53.
45. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: framework and proposal of a new classification and case definition. *J Periodontol*. 2018;89(S1):S159-172.
46. El Sayed N, Rahim-Wöstefeld S, Stocker F, Behnisch R, Eickholz P, Pretzl B. The 2018 classification of periodontal diseases: its predictive value for tooth loss. *J Periodontol*. 2022;93(4):560-569.
47. Saydzai S, Buontempo Z, Patel P, et al. Comparison of the efficacy of periodontal prognostic systems in predicting tooth loss. *J Clin Periodontol*. 2022;49(8):740-748.

SUPPORTING INFORMATION

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

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