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A retrospective study on periodontal disease progression in private practice

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Abstract

Background: Only a handful of studies have assessed tooth loss risk in chronic periodontitis patients following active therapy and factors associated with it.

Aims: The aim of this retrospective study was to assess tooth loss in a cohort of chronic periodontitis patients undergoing maintenance care in a UK private practice setting.

Materials and Methods: One hundred chronic periodontitis patients treated with active periodontal therapy were followed up in supportive periodontal therapy (SPT) for at least 5 years. Tooth loss rates and the effect of patient and tooth factors on tooth loss were assessed. Existing patient-based prognosis systems and a novel tooth-based prognosis system were tested for their association with tooth loss.

Results: Excluding third molars, 34 teeth were extracted during SPT, with an overall average tooth loss of 0.06 teeth/patient/year (0.02 for periodontal reasons). Multivariable analysis showed that age, patient prognosis based on the Periodontal Risk Assessment system, tooth prognosis, furcation involvement and previous endodontic therapy were significantly associated with tooth loss during SPT.

Conclusion: Good overall stability and a small tooth loss rate were observed in this cohort of chronic periodontitis cases under SPT in private practice. Patient-based and tooth-based prognosis systems may be used to estimate the risk of tooth loss.

Key words: maintenance; periodontitis; progression; stability

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The ultimate aim of periodontal treatment and an important health need worldwide is the maintenance of the tooth in a functional state. However, while a plethora of studies showing short-term treatment outcomes (6–12 months) are available in the literature, still comparatively few studies have been published on long-term tooth survival in periodontitis cases, and none to the best of our knowledge in UK populations. Risk of progression has been reported to be associated with smoking, diabetes, age, genetic variants, poor oral hygiene, residual probing pocket depths (PPDs), furcation involvement (FI) and provision and duration of supportive periodontal therapy (SPT; Hirschfeld & Wasserman 1978, McGuire & Nunn 1996, Chambrone & Chambrone 2006, Faggion et al. 2007, Eickholz et al. 2008, Matuliene et al. 2008). A recent systematic review (Lang et al. 2015) highlighted that very few adequately sized prospective studies can give evidence to inform maintenance therapy according to individual risk profiles (Costa et al. 2012).

The aim of this study was to assess periodontal disease progression in a cohort of patients with chronic periodontitis undergoing maintenance care in a private

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practice setting in the UK. In particular, we aimed to assess rates of tooth loss, factors associated with it and both patient-based and tooth-based prognosis systems.

Material and Methods

Patient population

One hundred consecutive patients with at least 5 years of maintenance care were selected 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 from 2003 to 2009. 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 14 LO 0629). The following inclusion criteria were considered for patient recruitment:

- Diagnosis of chronic periodontitis (Lindhe et al. 1999) with inter-proximal attachment loss ≥3 mm in at least two non-adjacent teeth (Tonetti & Claffey 2005).
- At least two sites with ≥5 mm PPDs and radiographic evidence of bone loss ≥20% of root length at first visit.
- Treated by author LN with non-surgical periodontal treatment with or without subsequent periodontal surgeries.
- Assessed at least once per year during maintenance care by the same author (therefore, patients with good compliance).
- Reassessed at least 5 years after completion of initial therapy.

Clinical examinations

Clinical and radiographic data from all patients were retrieved and the following visits and procedures were retrospectively identified in their records:

- Visit 1 (baseline). Self-reported patient medical and smoking histories were recorded (for a definition of "former smoker" patients had to have given up smoking at least 5 years before this visit). 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, dichotomous 6-point bleeding on probing (FMBS; Guerrero et al. 2005), tooth mobility (Laster et al. 1975) and FI (Hamp et al. 1975). Clinical attachment level (CAL) was calculated as PPD + REC. Clinical parameters were assessed by probing with a UNC-15 periodontal probe and a "Nabers" probe for FI. Dental radiographs of each patient had been obtained as necessary for diagnosis and treatment planning purposes at this visit. Following the clinical and radiographic assessments, a diagnosis was assigned and an initial treatment plan was agreed upon with the patient.
- Active periodontal therapy (APT) was defined as oral hygiene instructions and non-surgical supra- and sub-gingival debridement followed by, when indicated, additional periodontal surgery (including resective, regenerative or periodontal plastic surgery) and conservative, endodontic and prosthetic treatment if necessary. Some patients received adjunctive therapy during APT, consisting of systemic or local antibiotics. According to the initial treatment plan, teeth which were considered to have unfavourable/hopeless prognosis were extracted during APT.
- Visit 2 (start of SPT): Patients were assessed 3–6 months following completion of APT (end of APT) and the same clinical and radiographic procedures as performed at baseline were carried out. If the periodontal conditions were considered "stable" and not requiring further surgical therapy, patients were entered in the maintenance phase. This was generally achieved when no residual PPDs > 5 mm and no FMBS > 20% were detected.
- Supportive periodontal therapy followed an individualized interval of 3–12 months and consisted of medical and dental history updates, clinical and (if considered necessary) radiographic data collection as above, oral hygiene re-instructions and motivation and supra- and sub-gingival debridement (under local anaesthesia when necessary). Additional visits with the hygienists were arranged for some of the patients. If deterioration in periodontal parameters was detected, further treatment (including periodontal surgeries, extractions or endodontic therapy) was carried out. Criteria for defining "deterioration" were usually deepening PPDs or worsening recessions or FI over more than one appointment, or alternatively, appearance of symptoms of endodontic origin.
- Visit 3 (last follow-up): This consisted of the last clinical assessment of the patients when the retrospective analysis was conducted (June 2015) and the same diagnostic procedures as visit 1 and 2 were carried out.

Calculation of tooth loss

Total number and percentage of tooth loss during active (APT) and SPT including and excluding third molars was obtained from the patients' records. The time and reason for tooth loss had been documented in all cases and were used for analysis. Annual tooth loss rates in SPT were calculated by dividing number of teeth lost by months after start of SPT.

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) as described before (Nibali et al. 2011) at all comparable sites (mesial and distal) to calculate percentage of bone loss by root length. The presence of existing restorations and previous endodontic treatment were also recorded.

Assignment of tooth prognosis

Tooth prognosis was retrospectively assigned to all teeth with available

clinical and radiographic data. In the absence of a universally validated objective method for assigning tooth prognosis, the following variables were adapted from previous literature (Becker et al. 1984, Machtei et al. 1989, McGuire & Nunn 1996, Graetz et al. 2011, see Supporting information 1 for more details) and used for assigning tooth prognosis:

- Probing pocket depth (≤6 or >6 mm).
- Furcation involvement (grade I, II or III) (Hamp et al. 1975).
- Mobility (grade I, II or III) (Laster et al. 1975).
- Bone loss (percentage of alveolar bone loss/root length).
- Periapical pathology (periapical index, PAI, score of 5) (Ørstavik et al. 1986).
- Restorability (Esteves et al. 2011).

Hence, tooth prognosis was assigned following the objective criteria described in Fig. 1 (details of the indices used are presented in Supporting information 2).

Assignment of patient prognosis

The patient-based prognosis was assigned based on previously validated prognosis systems Periodontal Risk Assessment (PRA; Lang & Tonetti 2003) and Periodontal Risk Calculator (PRC, PreViser; Page et al. 2002), taking into account a combination of patient- and tooth-based variables.

Examiner calibration

Reproducibility of clinical and radiographic examinations and prognosis assignment is described in Supporting information 3.

Statistical analysis

Data from all patients were entered into a spreadsheet and proofed for entry errors. Continuous variables are reported as means and standard deviations. The primary outcome of the study was tooth loss. Secondary outcomes were changes in periodontal clinical parameters (FMPS, FMBS, average PPD, REC and CAL, percentage of teeth with PPD 1–4, 5–6 and >6 mm) and radiographic bone levels. A one-sample *t*-test was used to detect significant changes between baseline and re-evaluation for FMPS, FMBS, average PPD, average CAL and PPD subcategories.

Patient-level analysis

In the patient-level data analysis, two outcomes were evaluated. The primary outcome was the incidence of tooth loss with third molars excluded during SPT. The secondary outcome was the number of teeth lost during SPT. Logistic regression was used to evaluate the associations between the incidence of tooth loss and potential risk factors (results presented as odds ratios, ORs). Poisson regression was used to evaluate the associations between the number of teeth lost and potential risk factors (results presented as incidence rate ratios, IRRs).

Tooth-level analysis

In the tooth-level data analysis, we used generalized estimating equations (GEE) to estimate the associations between the incidence of tooth loss (with third molars excluded) and potential risk factors (results presented as ORs) for tooth-level data. This is because GEE can take into account the correlations among teeth within the same patient. All analyses used two-sided tests, and the level of statistical significance was set at 5%. Due to concern of collinearity between PPD and CAL, we only included CAL in either patient-level or tooth-level analysis. For the same concern of collinearity between endodontic therapy (yes *versus* no) and restored tooth (yes *versus* no), we only included endodontic therapy in the tooth-level analysis. In the tooth prognosis system, categories "good" and "fair" were grouped for analysis (against "questionable" and "unfavourable"). All statistical analysis was performed using STATA, version 14 (StataCorp LP, College Station, Texas, USA).

Results

Baseline characteristics

Table 1 reports baseline demographic and clinical characteristics of all patients included in the study. The great majority of patients were Caucasians (93%), prevalently female and with an average age of 53 years. The majority of patients (58%) had never smoked, while 22% were former smokers (having given up smoking on average 15 years before baseline) and 20% current smokers at baseline (smoking an average 12 cigarettes/day for 29 years). A total of 30 patients reported a diagnosis of a medical condition, the most common

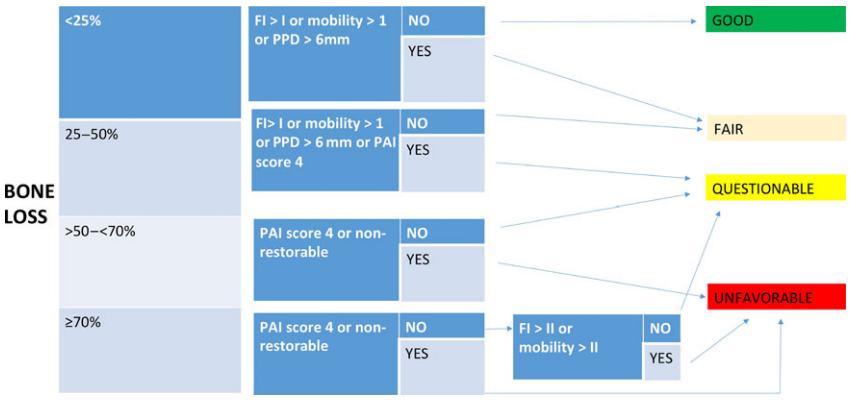

Fig. 1. Diagram showing the "tooth prognosis" system used in this study. FI, furcation involvement; PPD, probing pocket depth; PAI, periapical index.

Table 1. Demographic data of patients. Average and standard deviation are reported for age

	Frequency	Average
Age		53.04 ± 9.31
Gender		
Male	40	–
Female	60	–
Ethnicity		
White	93	–
Asian	5	–
Afro-Caribbean	2	–
Smoking status		
Never smoker	58	–
Current smoker	22	–
Former smoker	20	–

being hypertension (13%). No patients with diagnosed diabetes mellitus (DM) were present in this cohort. The total observation period during SPT was 79.1 ± 18.0 months (range 60–123 months). Table 2 shows clinical characteristics at the three study time-points (baseline, start of SPT and last follow-up visit).

Disease progression

During the course of the study, six patients gave up smoking, while 17 patients were diagnosed with a medical condition (in one case, DM). Patients attended an average 13.4 ± 6.8 visits with the treating periodontist (average 2 visits/patient/year) and an average 2 visits/year with the hygienist. Average PPD, average CAL, percentage of PPD 5–6 mm and percentage PPD >5 mm, FMPS and FMBS – all significantly decreased between baseline and visit 2 (end of APT) ($p < 0.001$) and then remained largely stable throughout SPT, with the exception of FMBS, which showed a further decrease from the end of APT to last follow-up ($p < 0.001$). The percentage of PPD 1–4 mm improved significantly during APT ($p < 0.001$) and then remained stable up to the last assessment. Average recession increased significantly during APT (0.6 *versus* 0.7 mm, $p < 0.001$), while no significant changes were observed during SPT.

Tooth loss during APT

Table 3 reports information on tooth loss throughout the observation period. Patients had a total of 70 teeth extracted during APT (considered hopeless or irrational to treat). Excluding third molars, the number of teeth extracted during APT was 45 (37 for periodontal, seven for endodontic reasons and one for oral hygiene access reasons). On a patient-level, 31 patients had teeth extracted during APT (range 1–8 teeth), although 11 of them only had third molars extracted.

Tooth loss during SPT

A total of 45 teeth were extracted during SPT (34 excluding third molars), while 46 dental implants were placed during SPT. Excluding third molars, reasons for tooth loss during SPT were periodontal disease ($n = 11$), fractures ($n = 11$), endodontic pathology ($n = 9$) and root caries ($n = 3$). Excluding third molars, the overall average tooth loss during SPT was 0.06 teeth/patient/year (0.08 teeth/patient/year including third molars), while average tooth loss for periodontal reasons during SPT was 0.02 teeth/patient/year (0.04 teeth/patient/year including third molars) (Supporting information 4). A total of 26 teeth were lost in the first 5 years of follow-up (0.05 teeth/patient/ year). Twenty-seven patients experienced tooth loss during SPT (range 1–4 teeth), out of which four only had third molars extracted. Overall, 115 teeth (1.1/patient) were extracted from baseline to the last visit, including APT and SPT (total follow-up average 82.3 months). Excluding third molars, upper molars were the teeth most commonly lost during APT and SPT combined ($n = 32$), followed by lower molars ($n = 18$), upper anteriors ($n = 12$), lower premolars ($n = 8$), upper premolars ($n = 7$) and lower anteriors ($n = 3$) (Supporting information 5).

Patient-level analysis of factors associated with risk of tooth loss

Table 4 presents the association between risk factors and tooth loss during SPT (presence or absence of tooth loss per patient with the exclusion of third molars). Owing to some missing clinical parameters, a total of 98 patients and 2395 teeth were included in the final analyses. In the univariable logistic regression analyses, age at baseline and baseline average CAL were associated with higher risk of incidence of tooth loss. No statistically significant associations were found for both prognosis based on PRA system and on PRC system and incidence of tooth loss. In the multivariable logistic regression model with all covariates (end of APT) included, only age (OR = 1.11; 95% CI = 1.02–1.21, $p = 0.001$) was significantly associated with tooth loss.

Patient-level analysis of factors associated with the number of teeth lost

Table 5 presents the association between risk factors and the number of teeth lost during SPT. Before adjusting for other covariates, Poisson regression showed that age and average CAL at start of SPT were

Table 2. Clinical characteristics at the three study time-points. Averages and standard deviations are reported for continuous variables

	Baseline		Start of SPT		Last visit	
	Number	Average	Number	Average	Number	Average
Number of teeth	2633	26.3 ± 4.0	2563	25.6 ± 4.2	2518	25.2 ± 4.4
Number of teeth (except 8s)	2494	24.9 ± 3.6	2449	24.5 ± 3.8	2415	24.3 ± 4.1
Number of implants	23	0.2 ± 0.9	23	0.2 ± 0.9	69	0.7 ± 1.8
FMPS (%)	–	25.4 ± 18.4	–	12.2 ± 11.7	–	12.9 ± 10.4
FMBS (%)	–	24.8 ± 15.1	–	8.3 ± 6.0	–	5.6 ± 4.4
Average PPD	–	2.8 ± 0.2	–	2.2 ± 0.4	–	2.2 ± 0.4
Average CAL	–	3.2 ± 1.3	–	2.8 ± 1.1	–	2.7 ± 1.2
% PPDs 1–4 mm	–	85.5 ± 17.0	–	97.0 ± 14.2	–	98.1 ± 10.4
% PPDs 5–6 mm	–	10.0 ± 7.9	–	2.7 ± 3.5	–	2.5 ± 3.1
% of PPDs >6 mm	–	4.5 ± 5.4	–	0.3 ± 0.8	–	0.4 ± 0.8

CAL, clinical attachment level; FMBS, full mouth bleeding score; FMPS, full mouth plaque score; PPD, probing pocket depth; SPT, supportive periodontal therapy.

Table 3. Number of teeth extracted during the study and percentage per patient (in brackets)

Teeth extracted	All teeth (per patient)	Excluding 8s (per patient)
During APT	70 (0.7 ± 1.5)	45 (0.5 ± 1.3)
During SPT	45 (0.4 ± 0.8)	34 (0.3 ± 0.7)
Total	115 (1.15 ± 1.6)	79 (0.8 ± 1.4)

APT, active periodontal therapy; SPT, supportive periodontal therapy.

Table 4. Odds ratios of tooth loss during SPT (patient-level data). Model 1 included gender, smoking, age, average FMPS, average FMBS, average CAL and prognosis based on PRA system. Model 2 included gender, smoking, age, average FMPS, average FMBS, average CAL and prognosis based on PreViser system

	Univariate		Model 1		Model 2	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Gender (male)	1.64 (0.65, 4.15)	0.294	2.55 (0.77, 8.43)	0.126	2.56 (0.80, 8.25)	0.115
Smoking	1.83 (0.72, 4.64)	0.201	2.81 (0.76, 10.43)	0.122	2.92 (0.86, 9.99)	0.087
Age	1.08 (1.02, 1.14)	0.010	1.15 (1.06, 1.24)	0.001	1.16 (1.07, 1.27)	0.001
FMPS	0.99 (0.96, 1.04)	0.794	0.98 (0.93, 1.05)	0.608	0.99 (0.93, 1.05)	0.666
FMBS	1.01 (0.94, 1.10)	0.704	1.10 (0.97, 1.22)	0.131	1.09 (0.97, 1.22)	0.150
Av. CAL	1.71 (1.09, 2.69)	0.020	1.75 (0.96, 3.19)	0.066	1.62 (0.93, 2.81)	0.088
PRA prognosis	1.11 (0.83, 1.49)	0.464	0.98 (0.61, 1.58)	0.935		
PreViser prognosis	1.03 (0.67, 1.59)	0.884			1.32 (0.72, 2.44)	0.365

CAL, clinical attachment level; PRA, Periodontal Risk Assessment; SPT, supportive periodontal therapy.

Table 5. IRRs of tooth loss during SPT (patient-level data). Model 1 included gender, smoking, age, average FMPS, average FMBS, average CAL and prognosis based on PR system. Model 2 included gender, smoking, age, average FMPS, average FMBS, average CAL and prognosis based on PreViser system

	Univariate		Model 1		Model 2	
	IRR (95% CI)	*p* value	IRR (95% CI)	*p* value	IRR (95% CI)	*p* value
Gender (male)	1.33 (0.69, 2.58)	0.396	2.00 (0.95, 4.18)	0.068	1.63 (0.80, 3.34)	0.182
Smoking	1.48 (0.76, 2.88)	0.244	1.58 (0.70, 3.58)	0.274	2.02 (0.96, 4.27)	0.064
Age	1.06 (1.03, 1.10)	0.001	1.11 (1.06, 1.16)	<0.001	1.10 (1.05, 1.15)	<0.001
FMPS	0.99 (0.96, 1.02)	0.516	0.98 (0.95, 1.03)	0.447	0.98 (0.94, 1.02)	0.247
FMBS	1.01 (0.95, 1.06)	0.778	1.04 (0.97, 1.21)	0.276	1.06 (0.99, 1.14)	0.089
Av. CAL	1.44 (1.08, 1.91)	0.012	1.17 (0.82, 1.67)	0.390	1.38 (0.97, 1.95)	0.072
PRA prognosis	1.22 (1.00, 1.48)	0.053	1.37 (1.02, 1.85)	0.038	–	–
PreViser prognosis	0.94 (0.69, 1.26)	0.669	–	–	1.04 (0.69, 1.55)	0.860

CAL, clinical attachment level; IRR, incidence rate ratio; PRA, Periodontal Risk Assessment; SPT, supportive periodontal therapy.

associated with an increased risk for the number of teeth lost during SPT. The IRRs of prognosis based on PRA and on PRC system were not statistically significant. In the multivariable Poisson model with all covariates included, age (IRR = 1.11; 95% CI = 1.06–1.16, $p < 0.001$) and prognosis based on PRA system (IRR = 1.37; 95% CI = 1.02–1.85, $p = 0.038$) were significantly associated with tooth loss.

Tooth-level analysis of factors associated with tooth loss incidence

Table 6 presents the associations between clinical risk factors at visit 2 (start of SPT) and incidence of tooth loss using tooth-level data. Before adjusting for other covariates, GEE analyses showed that age, CAL, FI and prognosis at visit 2 were associated with a higher risk of incidence of tooth loss. In the multivariable GEE analysis, the associations for age (IRR = 1.08; 95% CI = 1.03–

Table 6. Odds ratios of tooth loss during SPT (tooth-level data). Model 1 included gender, smoking, age, CAL, furcation and prognosis. Model 2 included gender, smoking, age, CAL, furcation, endodontic therapy, percentage of bone loss and prognosis

	Risk factors (visit 2) (only including clinical measurement variables, $n = 2314$)				Risk factors (baseline) (including clinical and X-ray measurement variables, $n = 1020$)			
	Univariate		Model 1		Univariate		Model 2	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Gender (male)	1.31 (0.59, 2.90)	0.507	1.47 (0.70, 3.08)	0.311	1.69 (0.78, 3.63)	0.181	1.02 (0.46, 2.29)	0.954
Smoking	1.53 (0.69, 3.40)	0.298	2.01 (0.91, 4.45)	0.083	1.31 (0.61, 2.82)	0.489	2.00 (0.87, 4.62)	0.105
Age	1.06 (1.02, 1.11)	0.003	1.08 (1.03, 1.13)	0.001	1.07 (1.03, 1.12)	0.001	1.10 (1.05, 1.16)	<0.001
CAL	1.59 (1.37, 1.84)	<0.001	1.12 (0.93, 1.36)	0.228	1.37 (1.19, 1.57)	<0.001	1.04 (0.82, 1.31)	0.771
Furcation	11.24 (5.53, 22.85)	<0.001	4.98 (2.20, 11.25)	<0.001	6.79 (3.23, 14.27)	<0.001	3.66 (1.55, 8.67)	0.003
Prognosis	13.57 (6.63, 27.77)	<0.001	4.52 (1.79, 11.40)	0.001	6.92 (3.04, 15.75)	<0.001	3.21 (1.01, 10.23)	0.049
Endodontic therapy	–	–	–	–	15.53 (7.31, 32.99)	<0.001	14.79 (6.14, 35.66)	<0.001
Percentage of bone loss	–	–	–	–	1.05 (1.03, 1.07)	<0.001	1.02 (0.99, 1.05)	0.142

CAL, clinical attachment level; SPT, supportive periodontal therapy.

1.13, $p = 0.001$), FI (IRR = 4.98; 95% CI = 2.20–11.25, $p < 0.001$) and tooth prognosis (IRR = 4.52; 95% CI = 1.79–11.40, $p = 0.001$) remained statistically significant. In the analysis of teeth for which both clinical and radiographic measurement variables were available, age (IRR = 1.10; 95% CI = 1.05–1.16, $p < 0.001$), FI (IRR = 3.66; 95% CI = 1.55–8.67, $p = 0.003$), tooth prognosis at start of SPT (IRR = 3.21; 95% CI = 1.01–10.23, $p = 0.049$) and previous endodontic therapy (IRR = 14.79; 95% CI = 6.14–35.660, $p < 0.001$) were significantly associated with the risk of tooth loss.

Discussion

This study retrospectively investigated disease progression and tooth loss in a cohort of chronic periodontitis patients undergoing SPT in a UK private practice. Results of this study show a small incidence of tooth loss over the 6.2 average years (75 months) of SPT. Patients in this study lost an average 0.06 teeth/patient/year (0.02 for periodontal reasons excluding third molars), very similar to previously reported figures of 0.05 teeth/patient/year (0.02 for periodontal reasons; Chambrone & Chambrone 2006) and 0.04 teeth/patient/year for periodontal reasons (Fardal & Linden 2005). A recent systematic review reported a mean yearly tooth loss rate of 0.15 and 0.09 during SPT with follow-up of 5 or 12–14 years respectively (Trombelli et al. 2015). Overall 4.3% of teeth were extracted in this study (2.6% during APT and 1.7% during SPT). This figure is considerably less with 14.4% of teeth extracted during the course of periodontal therapy (approximately half during APT and the other half during SPT) in a previous study (Matuliene et al. 2008). However, differences in initial disease severity may partially explain these discrepancies. For example, in the study by Matuliene et al., patients had 4.0 mm baseline average PPD (compared with 2.8 mm in this study) and lost 3.5 teeth/patient during APT and SPT combined (compared with 1.1 in this study). Studies with similar disease severity (e.g. König et al. 2002: 2.9 mm average PPD at the end of APT), showed more comparable results to the present study (0.07 teeth/patient/year lost during 10 years of SPT). In this group of compliant patients, overall periodontal stability was detected during SPT, with no significant changes in PPD, CAL, bleeding and plaque scores throughout follow-up period, following reductions during APT.

No cases of "extreme downhill" progression (Hirschfeld & Wasserman 1978) with loss of many teeth during SPT were observed in this study. A systematic review of longitudinal studies in chronic periodontitis had highlighted that age, smoking and initial tooth prognosis were found to be associated with tooth loss (Chambrone et al. 2010). In this study, age was associated with tooth loss during SPT, while smoking did not show a statistically significant influence on tooth loss. The effect of age on risk of tooth loss has been previously observed in most previous longitudinal studies (Chambrone & Chambrone 2006, Eickholz et al. 2008, Pretzl et al. 2008) but not universally (Faggion et al. 2007). The lack of a statistically significant effect of smoking (despite a trend for association with tooth loss) is at odds with some previous studies (McGuire & Nunn 1996, Eickholz et al. 2008, Matuliene et al. 2008) but in agreement with the results of another study by our group, investigating tooth loss in aggressive periodontitis (AgP; Dopico et al. 2016); we can hypothesize that this may be due to the small number of smokers present in these studies (12% in the AgP study and 22% in this study), which reduces the power to show a statistically significant effect. Similarly, oral hygiene (measured as full mouth plaque score at start of SPT) was not associated with tooth loss in this patient cohort. However, we must acknowledge that one single plaque score at the start of SPT may not accurately reflect oral hygiene compliance throughout the study. No data on body mass index and socio-economic status were available in this study; hence, we could not test their potential effects on periodontal progression and tooth loss.

Among tooth factors, clinical attachment loss, FI and previous endodontic treatment were significantly associated with tooth loss. Periodontal disease severity is clearly associated with further progression and tooth loss (Badersten et al. 1981, 1984 McGuire & Nunn 1996). CAL, rather than PPD, was used in the final statistical model in the current paper, owing to a stronger association with the tooth loss outcome in the univariate analysis. The risk of tooth loss for molars with FI undergoing SPT was estimated to be 2–4 times higher than molars with no FI in a recent systematic review (Nibali et al. 2016) and this was confirmed in the current paper. Specific details and data on furcation treatment will be presented in a separate publication. The association of previous endodontic treatment and tooth loss was particularly pronounced in this study (nine teeth were extracted for what was judged as recurrent endodontic pathology). This is in agreement with a recent study reporting a 35% likelihood that root-filled teeth would be lost within 20 years (Petersson et al. 2016) and stressed the importance of an overall prognosis system, which takes into account periodontal as well as endodontic and restorative considerations for formulating tooth prognosis.

In a similar study to the present one, developing a tooth prognosis system, McGuire & Nunn (1996) had suggested that tooth loss is only partially reflected in the assigned prognosis, and that a more accurate method for the assignment of prognosis needed developing. Risk assessment tools have been published and validated to help identify high-risk subjects and tailor maintenance care accordingly (Page et al. 2003, Lang & Tonetti 2003). Therefore, we tested two of the most-widely used prognosis systems, the PRA and the PRC tools (reviewed by Lang et al. 2015) and we also developed an objective tooth prognosis scale. In this study, only the PRA system showed a statistically significant association with the number of teeth lost during SPT. This is in agreement with previous longitudinal studies, showing its potential use for patient-based risk assessments (Matuliene et al. 2008, Costa et al. 2012, Meyer-Bäumer et al. 2012). However, tooth loss prediction on an individual basis remains a very difficult task, owing to many variables potentially affecting it.

A specific tooth-prognosis system was developed and applied to the present dataset (see Fig. 1). This included bone loss (proportion of alveolar bone loss/root length), PPD (≤6 or >6 mm), FI (Hamp et al. 1975), mobility (Laster et al. 1975), periapical pathology (Ørstavik et al. 1986) and restorability (Esteves et al. 2011), and divided teeth into good and fair (grouped for the final analysis), questionable and unfavourable prognoses. Compared with previous studies, diagnostic criteria were more objective (leaving no space for personal interpretation) and the criteria for "unfavourable" prognosis were quite severe, reflecting a conservative treatment philosophy, aimed at tooth retention. A strong association was detected between this prognosis system and tooth loss during SPT, suggesting its potential usefulness in predicting tooth prognosis, possibly combined with patient-based risk tools.

Although not comparing different maintenance regimes, this study reenforces the importance of SPT for tooth retention. Patients in this study were seen on average every 6 months by the treating periodontist (in addition to hygienist visits), confirming that a maintenance programme based on oral hygiene instructions and professional plaque control every 4–6 months can effectively minimize tooth loss for periodontal reasons (Axelsson et al. 2004, Lee et al. 2015).

The strength of this study lies in the homogeneity of periodontal assessments and treatment (initial and supportive care), all carried out by the same periodontist, exact measures of time and reason for tooth loss, the use of GEE analysis to take into account patient and tooth factors and the novelty of providing tooth loss data in a UK chronic periodontitis population in a private setting. In addition, the private practice environment is important in order to assess the generalizability of the benefit to these specific prognoses systems. Limitations include its retrospective nature, the lack of patient-reported outcomes and information on other potential risk factors such as body mass index. In particular, owing to this study design, both exposure and outcome have been assessed in retrospect, and subjects with poor compliance may have been automatically excluded for not attending recalls, introducing potential selection bias. In conclusion, this study confirms that patients with moderate to severe chronic periodontitis under SPT undergo a low risk of tooth loss, suggests the use of combined patient-based and tooth-based prognoses systems, and also reiterates the need for prospective studies in periodontitis patients in maintenance.

References

Axelsson, P., Nyström, B. & Lindhe, J. (2004) The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. *Journal of Clinical Periodontology* **31**, 749–757.

Badersten, A., Nilveus, R. & Egelberg, J. (1984) Effect of nonsurgical periodontal therapy. II. Severely advanced periodontitis. *Journal of Clinical Periodontology* **11**, 63–76.

Badersten, A., Nilvéus, R. & Egelberg, J. (1981) Effect of nonsurgical periodontal therapy. I. Moderately advanced periodontitis. *Journal of Clinical Periodontology* **8**, 57–72.

Becker, W., Becker, B. E. & Berg, L. E. (1984) Periodontal treatment without maintenance. A retrospective study in 44 patients. *Journal of Periodontology* **55**, 505–509.

Chambrone, L. A. & Chambrone, L. (2006) Tooth loss in well-maintained patients with chronic periodontitis during long-term supportive therapy in Brazil. *Journal of Clinical Periodontology* **33**, 759–764.

Chambrone, L., Chambrone, D., Lima, L. A. & Chambrone, L. A. (2010) Predictors of tooth loss during long-term periodontal maintenance: a systematic review of observational studies. *Journal of Clinical Periodontology* **37**, 675–684.

Costa, F. O., Cota, L. O., Lages, E. J., Lima Oliveira, A. P., Cortelli, S. C., Cortelli, J. R., Lorentz, T. C. & Costa, J. E. (2012) Periodontal risk assessment model in a sample of regular and irregular compliers under maintenance therapy: a 3-year prospective study. *Journal of Periodontology* **83**, 292–300.

Dopico, J., Nibali, L. & Donos, N. (2016) Disease progression in aggressive periodontitis patients. A retrospective study. *Journal of Clinical Periodontology* **43**, 531–537.

Eickholz, P., Kaltschmitt, J., Berbig, J., Reitmeir, P. & Pretzl, B. (2008) Tooth loss after active periodontal therapy. 1: patient-related factors for risk, prognosis, and quality of outcome. *Journal of Clinical Periodontology* **35**, 165–174.

Esteves, H., Correia, A. & Araújo, F. (2011) Classification of extensively damaged teeth to evaluate prognosis. *Journal of the Canadian Dental Association* **77**, 105.

Faggion, C. M. Jr, Petersilka, G., Lange, D. E., Gerss, J. & Flemmig, T. F. (2007) Prognostic model for tooth survival in patients treated for periodontitis. *Journal of Clinical Periodontology* **34**, 226–231.

Fardal, O. & Linden, G. J. (2005) Re-treatment profiles during long-term maintenance therapy in a periodontal practice in Norway. *Journal of Clinical Periodontology* **32**, 744–749.

Graetz, C., Dorfer, C. E., Kahl, M., Kocher, T., Fawzy El-Sayed, K., Wiebe, J. F., Gomer, K. & Ruhling, A. (2011) Retention of questionable and hopeless teeth in compliant patients treated for aggressive periodontitis. *Journal of Clinical Periodontology* **38**, 707–714.

Guerrero, A., Griffiths, G. S., Nibali, L., Suvan, J., Moles, D. R., Laurell, L. & Tonetti, M. S. (2005) Adjunctive benefits of systemic amoxicillin and metronidazole in non-surgical treatment of generalized aggressive periodontitis: a randomized placebo-controlled clinical trial. *Journal of Clinical Periodontology* **32**, 1096–1107.

Hamp, S., Nyman, S. & Lindhe, J. (1975) Periodontal treatment of multirooted teeth. Results after 5 years. *Journal of Clinical Periodontology* **2**, 126–135.

Hirschfeld, L. & Wasserman, B. (1978) A long-term survey of tooth loss in 600 treated periodontal patients. *Journal of Periodontology* **49**, 225–237.

König, J., Plagmann, H. C., Rühling, A. & Kocher, T. (2002) Tooth loss and pocket probing depths in compliant periodontally treated patients: a retrospective analysis. *Journal of Clinical Periodontology* **29**, 1092–1100.

Lang, N. P., Suvan, J. E. & Tonetti, M. S. (2015) Risk factor assessment tools for the prevention of periodontitis progression a systematic review. *Journal of Clinical Periodontology* **42**, 59–70.

Lang, N. P. & Tonetti, M. S. (2003) Periodontal risk assessment for patients in supportive periodontal therapy (SPT). *Oral Health & Preventive Dentistry* **1**, 7–16.

Laster, L., Laudenbach, K. & Stoller, N. (1975) An evaluation of clinical tooth mobility measurements. *Journal of Periodontology* **46**, 603–607.

Lee, C. T., Huang, H. Y., Sun, T. C. & Karimbux, N. (2015) Impact of patient compliance on tooth loss during supportive periodontal therapy: a systematic review and meta-analysis. *Journal of Dental Research* **94**, 777–786.

Lindhe, J., Ranney, R., Lamster, R. I., Charles, A., Chung, C., Flemming, T., Kinane, D., Listgarten, M., Löe, H., Schoor, R., Seymour, G. & Somerman, M. (1999) Consensus report: chronic periodontitis. *Annals of Periodontology* **4**, 38.

Machtei, E. E., Zubrey, Y., Yehuda, A. B. & Soskolne, W. A. (1989) Proximal bone loss adjacent to periodontally "Hopeless" teeth with and without extraction. *Journal of Periodontology* **60**, 512–515.

Matuliene, G., Pjetursson, B. E., Salvi, G. E., Schmidlin, K., Bragger, U., Zwahlen, M. & Lang, N. P. (2008) Influence of residual pockets on progression of periodontitis and tooth loss: results after 11 years of maintenance. *Journal of Clinical Periodontology* **35**, 685–695.

McGuire, M. K. & Nunn, M. E. (1996) Prognosis versus actual outcome. III. The effectiveness of clinical parameters in accurately predicting tooth survival. *Journal of Periodontology* **67**, 666–674.

Meyer-Bäumer, A., Pritsch, M., Cosgarea, R., El Sayed, N., Kim, T. S., Eickholz, P. & Pretzl, B. (2012) Prognostic value of the periodontal risk assessment in patients with aggressive periodontitis. *Journal of Clinical Periodontology* **39**, 651–658.

Nibali, L., Pometti, D., Tu, Y. K. & Donos, N. (2011) Clinical and radiographic outcomes following non-surgical therapy of periodontal infrabony defects: a retrospective study. *Journal of Clinical Periodontology* **38**, 50–57.

Nibali, L., Zavattini, A., Nagata, K., Di Iorio, A., Lin, G. H., Needleman, I. & Donos, N. (2016) Tooth loss in molars with and without furcation involvement – a systematic review

and meta-analysis. *Journal of Clinical Periodontology* **43**, 156–166.
Ørstavik, D., Kerekes, K. & Eriksen, H. M. (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics & Dental Traumatology* **2**, 20–34.
Page, R. C., Krall, E. A., Martin, J., Mancl, L. & Garcia, R. I. (2002) Validity and accuracy of a risk calculator in predicting periodontal disease. *Journal of the American Dental Association* **133**, 569–576.
Page, R. C., Martin, J., Krall, E. A., Mancl, L. & Garcia, R. (2003) Longitudinal validation of a risk calculator for periodontal disease. *Journal of Clinical Periodontology* **30**, 819–827.
Petersson, K., Fransson, H., Wolf, E. & Hakansson, J. (2016) Twenty-year follow-up of root filled teeth in a Swedish population receiving high-cost dental care. *International Endodontic Journal* **49**, 636–645.
Pretzl, B., Kaltschmitt, J., Kim, T. S., Reitmeir, P. & Eickholz, P. (2008) Tooth loss after active periodontal therapy. 2: tooth-related factors. *Journal of Clinical Periodontology* **35**, 175–182.
Tonetti, M. S. & Claffey, N. (2005) Advances in the progression of periodontitis and proposal of definitions of a periodontitis case and disease progression for use in risk factor research. Group C consensus report of the 5th European Workshop in Periodontology. *Journal of Clinical Periodontology* **32**, 210–213.
Trombelli, L., Franceschetti, G. & Farina, R. (2015) Effect of professional mechanical plaque removal performed on a long-term, routine basis in the secondary prevention of periodontitis. A systematic review. *Journal of Clinical Periodontology* **42**, 221–236.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Criteria previously used for assignment of tooth prognosis, from where criteria were adapted and selected for this study.

Appendix S2. Indices used to develop the tooth-prognosis index.
Table S1. Criteria previously used for assignment of tooth prognosis, from where criteria were adapted and selected for this study.
Table S2. Total numbers and average tooth loss during SPT.
Table S3. Teeth extracted in all patients (in brackets teeth extracted for periodontal.

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Clinical Relevance

Scientific rationale for the study: There is need to detect factors associated with tooth loss in patients during supportive periodontal therapy (SPT).
Principal findings: Patients with chronic periodontitis under regular SPT present with low tooth loss rates. Age and specific patient- and tooth-prognosis systems are associated with risk of tooth loss.
Practical implications: SPT leads to a low risk of tooth loss in chronic periodontitis patients. The risk of tooth loss per subject can be estimated using existing prognosis tools. A novel tooth prognosis system associated with tooth loss is proposed.