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Tooth loss in periodontally compromised patients: Retrospective long-term results 10 years after active periodontal therapy. Tooth-related outcomes

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Abstract

Background: Estimating prognosis of periodontally affected teeth at the beginning of supportive periodontal care (SPC) is an important component for further treatment planning. This study aimed to evaluate tooth loss (TL) during 10 years of SPC in periodontally compromised patients and to identify tooth-related factors affecting TL.

Methods: Patients were re-examined 120 ± 12 months after accomplishment of active periodontal therapy. TL was defined as primary outcome variable and tooth-related factors (abutment status, furcation involvement [FI], tooth mobility, mean periodontal probing depth [PD], and clinical attachment level [CAL] at beginning of SPC, and initial bone loss [BL]) were estimated based on an adjusted regression analyses model.

Results: Ninety-seven patients (51 females and 46 males; mean age, 65.3 ± 11 years) lost 119 of 2,323 teeth (overall TL [OTL]: 0.12 teeth/patient/y) during 10 years of SPC. Forty of these teeth (33.6%) were lost for periodontal reasons (TLP; 0.04 teeth/patient/y). Significantly more teeth were lost due to other reasons ($P < 0.0001$). TLP (OTL) only occurred in 5.9% (14.7%) of all teeth, when BL was at least 80%. Use as abutment tooth, FI degree III, tooth mobility degrees I and II, mean PD, and CAL positively correlated with OTL ($P < 0.05$). For TLP, FI and tooth mobility degree III as well as mean CAL were identified as tooth-related prognostic factors ($P < 0.05$).

Conclusions: During 10 years of SPC, most of the teeth (93.4%) of periodontally compromised patients were retained, showing the positive effect of a well-established treatment concept. Well-known tooth-related prognostic factors were confirmed.

KEYWORDS
humans, periodontal diseases, retrospective studies, risk factors, tooth loss, treatment outcome

1 | INTRODUCTION

The high prevalence of severe periodontal disease globally[1] and its consequences with regard to reduced esthetics,[2–4] function[2–4] up to tooth loss (TL),[2–4] and the resulting decrease in oral health–related quality of life[5] underline the significance of understanding and examining the multifactorial nature of periodontitis[2,3,6,7] on a clinical level in addition to basic research.

If patients have successfully undergone active periodontal therapy (APT), application of a systematic periodontal treatment concept encompasses allocation to supportive periodontal care (SPC).[8,9] After completion of APT, it can be assumed that TL during SPC, depending on its duration, is a rare event.[6–13] Today, the general relevance of SPC to facilitate long-term tooth retention is widely acknowlegded.[6–15] However, only a minor portion of these studies consider that SPC is a fundamentally periodontal treatment method, which primarily aims to prevent TL for periodontal reasons (TLP).[7,14,15] It is therefore important that studies on this topic cover long SPC periods and consider TLP so as to better assess the success of SPC. This is not easy, as there is no standardized definition of periodontally hopeless teeth. On the contrary, the limits of long-term tooth retention seem to be increasingly shifting to longer survival.[16] A large number of retrospective cohort studies in both, a university[6–8,10–14,17–21] as well as in a private practice setting[2,15,22,23] already exist, further long-term data are valuable, as they help to confirm and expand existing evidence and to incorporate therapy results of different concepts at different centers.

A distinction is made mainly at the level of data analysis between patient- and tooth-related data. However, prognostically, these data must always be considered together within a patient. The aim of this retrospective cohort study was to identify tooth-related factors (data on patient-related factors published previously[7]) for overall TL (OTL) and TLP in a homogeneously treated cohort over a period of 10 years.

2 | MATERIALS AND METHODS

Patient-related data from this cohort have recently been reported.[7] Selected data of the first 50 patients from this study were considered in a multicenter project.[8]

2.1 | Patients

After patients were identified by electronic and manual database searches by means of dental codes. They were invited consecutively, in the order of their treatment at that time, to a follow-up examination that took place 120 ± 12 months after APT completion until a number of about 100 patients was included.[3,13,22] Only those patients who had undergone anti-infective therapy after 2005 in the Department of Periodontology of the Johann Wolfgang Goethe-University Frankfurt/Main were considered for possible inclusion in this study. Further inclusion criteria were as follows:

- Complete periodontal status [periodontal probing depth (PD), clinical attachment level (CAL), bleeding on probing (BOP) at six sites/tooth; furcation involvement (FI)[24] at all furcation sites of multi-rooted teeth; tooth mobility[25] of all teeth before start of therapy (baseline, T0), and after completion of APT (non-surgical/step 2 and, if required, surgical/step 3 therapy[9]), and start of SPC (T1)
- Modified full-mouth disinfection concept (FMD)[26] was applied
- Age ≥18 years at the time of re-examination (T2)
- Panoramic radiograph or complete set of periapical radiographs from baseline
- T1−T2 = 120 ± 12 months

This study was approved by the Institutional Review Board for Human Studies of the Medical Faculty of the Johann Wolfgang Goethe-University (approval no. 61/15) and was conducted in accordance with the 1975 Declaration of Helsinki, as revised in 2013. All patients gave written consent for participation in this study. The study was registered with the United States National Library of Medicine clinical trials database (ClinicalTrials.gov; ID: NCT03048045).

2.2 | Applied treatment concept

The treatment concept adopted during the course of this study has already been described in detail.[7,26] At the beginning, all subjects received oral hygiene instructions and supragingival instrumentation. Afterward, subgingival instrumentation according to a modification[26] of the FMD concept was performed.[27] FMD was combined with adjunctive systemic antibiotics if *Aggregatibacter actinomycetemcomitans* was detected by different commercially available sets for taking subgingival plaque samples.[*,†,‡] If required (e.g., remaining PD ≥6 mm[9]), periodontal surgery was recommended. After completion of APT, patients

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‡ iai Pado Test; Institute for Applied Immunology IAI, Zuchwil, Switzerland.

were allocated to SPC according to the Periodontal Risk Assessment.[28] As a result, the risk-adapted SPC interval was determined prospectively in each individual SPC session.[3] This concept anticipates in large parts the actual clinical practice guideline for treatment of stages I, II, and III periodontitis.[9] SPC was encompassed consistently:[7]

1. Gingival bleeding index (GBI)[29] and plaque control record[30] at six sites/tooth
2. Re-instruction and re-motivation for effective individual biofilm control
3. Professional mechanical plaque removal
4. Application of fluoride gel[* 31]
5. Twice per year, a dental examination and a complete periodontal status assessment including PD, BOP, FI, and tooth mobility (some teeth have been splinted since T0) were recorded. Once per year, CAL was assessed. At sites with PD = 4 mm + BOP or PD ≥5 mm,[32] subgingival instrumentation was performed and 1% chlorhexidine digluconate gel[†] was instilled.

All treatments were performed in a university setting by dentists in collaboration with dental nurses or hygienists as well as by dental students under supervision of periodontists and postgraduate periodontics students. If a patient exhibited >5 teeth with PD ≥5 mm 2 years after re-evaluating APT, recurrence therapy was recommended, considering individual factors (e.g., patient age, systemic diseases).

2.3 | Variables evaluated at 10-year re-examination (T2)

Four experienced periodontists (KN, TR, PE, HP) were involved in patient re-examinations between July 2015 and April 2019. Interindividual calibration for PD and CAL by repeated measurements has been described in detail previously.[7]

Tooth-related factors included the following:

1. PD and CAL to the nearest 1.0 mm with a manual, millimeter-scaled rigid periodontal probe[‡] at six sites/tooth
2. BOP reported 30 seconds after probing
3. FI at all multi-rooted teeth with furcation probe[§ 24]
4. Tooth mobility at all teeth[25]

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5. Dental status (assessment of teeth lost during SPC, tooth type [anteriors, premolars, molars], and abutment status [no abutment tooth, fixed, or removable partial denture])

Patients who lost teeth during SPC were asked about the reason for this, if teeth were removed outside of the center.

The following patient-related factors were considered: 1) Self-reported smoking status (non-smoker [never smoked in their life], former smoker [stopped smoking ≥5 years ago], active smoker [including patients who stopped smoking <5 years ago]);[28] 2) Medical history; and 3) GBI[29] and plaque control record.[30]

2.4 | Radiographic examination

A panoramic radiograph or a complete set of periapical radiographs was available for each patient at T0 by one non-calibrated examiner (LP). Each tooth was assigned the highest mesial or distal bone loss (BL) according to one of five categories (≤20%, 21% to 40%, 41% to 60%, 61% to 80%, >80%) using a Schei Ruler.[33]

Variables evaluated using patients' charts

This study evaluated the following: 1) Medical history (diabetes status [including HbA1c]; smoking status [including number of cigarettes/day]); 2) Initial diagnosis of periodontal diseases (1999 classification),[34] reclassified according to the 2018 classification using T0 periodontal charts (staging: interproximal CAL, teeth missing due to periodontal reasons and complexity; grading: BL age index, smoking, diabetes);[35] 3) Periodontal charts between T1 and T2 (PD, CAL, BOP, FI, tooth mobility, for calculation of periodontal inflamed surface area [PISA] and periodontal epithelial surface area [PESA]);[36] 4) GBI[29] and plaque control record;[30] 5) Adherence (adherent/non-adherent) by comparing SPC interval recommendations with intervals actually documented in the patient's file (if patients once exceeded the recommended SPC interval by > 100%, they were considered to be non-adherent[3]); 6) SPC period and number of SPCs; and 7)Reasons for TL if tooth/teeth were removed in the authors' center (TLP: if a combination of progressive CAL loss, FI II/III,[24] and/or tooth mobility II/III[25] was found); since the documentation of extraction decisions over the past 10 years has not been uniform, the last clinical and radiological findings before the respective extraction were used—if reasons were not explicitly documented—to assess whether there were either periodontal or other reasons for TL.[7]
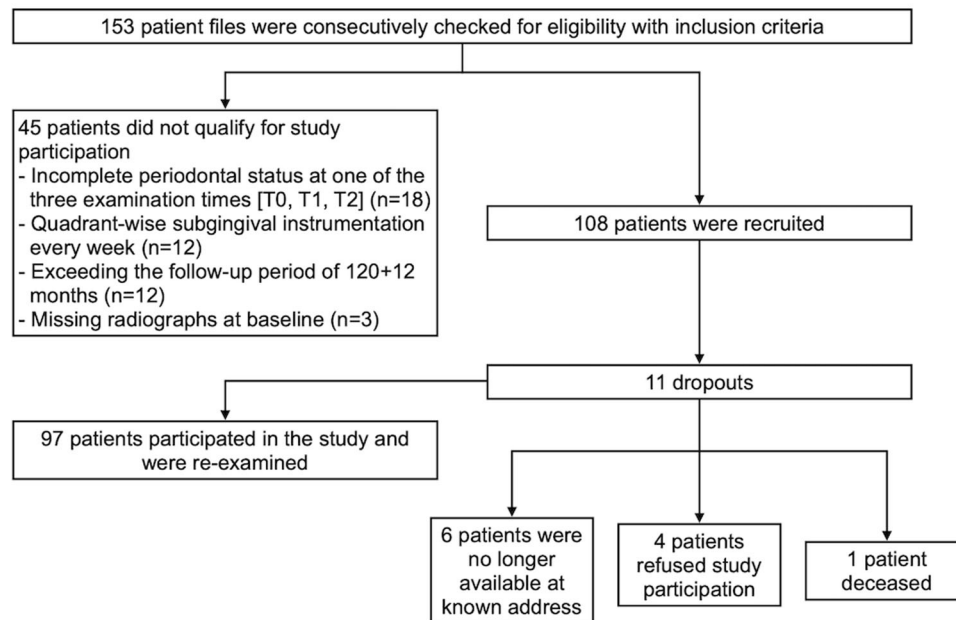
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FIGURE 1 Patient flow diagram

2.5 | Statistical analysis

Data of all subjects at T0, T1, and T2 were entered into a data matrix.[*] The patient was defined as the statistical unit and OTL/TLP during SPC as the main target variable. Third molars were excluded from data analysis.

Patient-specific characteristics were described using absolute (mean ± SD) and/or relative frequencies. Tooth-specific data were described separately at T0, T1, and T2 using absolute and relative frequencies. Univariate correlations of patient-related variables were performed for metrically scaled data using Pearson correlation coefficient and for nominally scaled data using the Chi-square test. Tooth-related data were compared by repeated-measures analysis of variance.

Two logistic multilevel regression models were calculated using "OTL" or "TLP" as dependent variables ("0" = tooth not lost; "1" = tooth lost) to identify tooth-related factors possibly affecting TL. Therefore, the level "teeth" (T1) was subordinated to the level "patient." As an indicator of how well the model fits the data, "-2 log likelihood" (-2LL) was calculated. Factors were included by significant binary logistic regression analysis. Collinearity was tested for all independent variables/factors by variance inflation factor showing VIF <2.1.[37] As tooth-related variables, abutment status, FI (most severe score per tooth), tooth mobility, BL, mean PD, and CAL of six sites/tooth were consid-

ered (all T1). As patient-related factors, mean BOP, GBI during SPC (for OTL and TLP), the number of SPCs, grading, and smoking at T1 (for TLP) were included into the model. PISA, PESA, and tooth type were not considered in the regression model due to collinearities (VIF >10).[37]

A significance level of 0.05 was assumed. The statistical evaluations were performed with appropriate software.[†]

3 | RESULTS

3.1 | Patients

Among 153 consecutively screened patient files, 45 patients were excluded due to violation of inclusion criteria. Twelve did not receive FMD, but instead received quadrant-wise subgingival instrumentation and were therefore excluded by deviation from the treatment concept. Of the remaining 108 patients, four denied participating in the study, six were no longer available at their known addresses, and one patient was deceased (Fig. 1).

Thus 97 patients (n = 51 female; 53%) with an average age of 55.2 ± 10.9 years at T1 were included. SPC lasted 10.2 ± 0.5 years on average. Fourteen patients (14%; T1) were

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[*] Excel version 16.23; Microsoft, Redmond, WA
[†] SPSS Statistics 24 software package; IBM, Chicago, IL

smokers and five (5%, T1) suffered from diabetes. Eleven patients received systemic antibiotics adjunctively to subgingival instrumentation (APT) (11%), 13 underwent recurrence therapy (13%), and 55 regularly participated in SPC (57%). Patients with TLP attended on average six appointments more than patients without TLP. Further patient-related data are depicted in Table 1.

3.2 | Teeth

At T1, there were 2,323 teeth (1,074 [46%] anteriors, 679 [29%] premolars, and 571 [25%] molars). A total of 734 teeth (32%) were multi-rooted, of which 392 (53%) showed FI; 305 teeth (13%) showed tooth mobility, and 503 teeth (22%) were used as abutment teeth. Of the initial 2,360 teeth (T0), 2,224 teeth could be evaluated radiographically. BL at 136 teeth could not be assessed due to overlapping. A total of 2,118 teeth (90%) showed BL ≤60% and only 34 teeth (1%) >80%. Tooth-related data are shown in Table 2. Percentage as well as absolute frequencies of PD and CAL and mean GBI, plaque control record, and BOP are described in Table 3. Results of interindividual calibration have been reported before.[7]

3.3 | Tooth loss

A total of 119 teeth were extracted during SPC (5.1%, 0.12 teeth/patient/y), including 40 (1.7%, 0.04 teeth/patient/y) for proven periodontal reasons. In terms of OTL (TLP) at patient-level, 23 (20) patients lost one to two teeth, 11 (2) patients lost three to four teeth, and eight (1) patients lost five to seven teeth. A total of 24 anteriors (20%), 36 premolars (30%), and 59 molars (50%) were lost, including five anteriors (12.5%), 10 premolars (25%), and 25 molars (62.5%) in the context of TLP, respectively (Table 2). Of all lost teeth, 39.5% (n = 47) were lost with an FI III, 43.7% (n = 52) with tooth mobility ≥I, and 52.1% (n = 62) as abutment teeth. TLP, on the other hand, occurred in 47.5% (n = 19) with an FI ≥I, 50% (n = 20) with tooth mobility ≥I, and 45% (n = 18) with a fixed partial denture (FPD). Regarding possible combinations of at least two tooth-related factors present at T1, it is noticeable that most teeth were lost for both OTL (n = 23; 19.3%) and TLP (n = 17; 42.5%) when combining FI ≥I with a tooth mobility ≥I (Table 4 and 6). More than half of the teeth were lost if they were used as abutment teeth with a removable partial denture (RPD) (n = 7; 53.8%) or if they showed FI = III (n = 3; 75%) at beginning of SPC (Tables 4 and 5). While TLP did not occur in RPD, all teeth with FI III were lost for periodontal reasons (Tables 4 and 5). Of all teeth (n = 35) with initial BL >80%,

14.3% (n = 5) were lost, two of them (5.7%) for periodontal reasons (Table 7).

Factors identified by binary logistic regression (see Supplementary Table S1 in online Journal of Periodontology) were correlated with OTL (-2LL: 11784.396) and TLP (-2LL: 11851.680) during multilevel logistic regression analysis. Fixed (P = 0.003) and removable (P = 0.002) abutment status, FI III (P = 0.006), tooth mobility degrees I (P = 0.002) and II (P = 0.018), and mean CAL (P = 0.044) as well as PD (P = 0.002) correlated positively with OTL (Table 8). For TLP, the respective factors were FI III (P = 0.0001), tooth mobility degree III (P = 0.003), and mean CAL (P = 0.031) (Table 9).

4 | DISCUSSION

In this retrospective TL analysis of a homogeneously treated cohort 119 teeth were lost (OTL, 5.1%; 0.12 teeth/patient/y), of a total of 2,323 teeth, 40 of them for periodontal reasons (TLP, 1.7%; 0.04 teeth/patient/y). For a long-term study after active treatment, it seems conclusive to choose TLP as primary target variable. Most long-term studies on this topic over similar and longer follow-up periods; however, report OTL.[2,11–13,18–20,22,38–40] Therefore, both types of TL were analyzed in the present study. A direct comparison of OTL and TLP is not intended and not possible because of the overlap (TLP is included in OTL).

All patients were treated in the APT according to a consistent treatment concept,[26] which compared with other investigations is a strength as therapeutic prerequisites were almost the same for the patients at the beginning of the follow-up examination period.[3,13] The annual TL rates for this study confirm the findings of previous investigations. In a recent study, 198 teeth were lost in 69 patients (12.3%) over a follow-up period of 20 years.[13] Looking at the 10-year data of this cohort, 84 teeth (5.2%; 0.12 teeth/patient/y) were lost. Further, comparable studies report a relative OTL ranging from 5.3% (0.13 teeth/patient/y) to 10.7% (0.14 teeth/patient/y).[11,12,18,22] It should be noted; however, that these studies either only include chronic[11] or aggressive[12,18,22] periodontitis (AgP) with correspondingly smaller patient numbers in case of AgP over follow-up periods between 10.5[18] and 24.2 years.[22] Moreover, they were performed in a university[11,12,18] or a practice setting.[22]

Limiting to TLP, the results with regard to TL vary between 1.5% and 4.0% with annual TL rates of 0.03 to 0.08 teeth/patient.[14,15,20,40] The varying number of cases, both up-[15] and downwards,[14] and the different follow-up periods between 9.6[40] and 20 years[15,20] are most likely to explain these differences. In addition to the different inclusion criteria there is no uniform definition of TLP, which varies by

TABLE 1 Patient characteristics

Variables	Total	All patients without OTL	All patients with OTL	P	All patients without TLP	All patients with TLP	P
Patients, n	97	50	47	0.452	74	23	0.452
Sex, n (female/male)	51/46	28/22	23/24	0.486	39/35	12/11	0.965
Age, years							
T0	54.07 ± 10.90	53.19 ± 10.73	55.02 ± 11.12	0.412	54.11 ± 10.83	53.97 ± 11.37	0.957
T1	55.16 ± 10.88	54.15 ± 10.65	56.22 ± 11.12	0.351	55.11 ± 10.75	55.32 ± 11.51	0.935
T2	65.33 ± 11.0	64.33 ± 10.68	66.39 ± 11.15	0.355	65.27 ± 10.81	65.52 ± 11.43	0.924
Smoking, n (T1)							
Active smoker	14	6	8	0.654	10	4	0.030
Former or non-smoker	83	44	39		64	19	
Diabetes, n	5	2	3	0.668	3	2	0.768
APT							
Initial diagnosis, n							
Stage III/Stage IV	76/21	43/7	33/14	0.036	58/16	18/5	0.471
Localized/generalized/MIP	20/71/6	10/34/6	10/37/0	0.379	16/52/6	4/19/0	0.086
Grade (A/ B/ C)	0/31/66	0/18/32	0/13/34	0.070	0/27/47	0/4/19	0.023
Duration, years	1.08 ± 0.66	0.97 ± 0.61	1.21 ± 0.69		0.10 ± 0.63	1.35 ± 0.67	
SPC							
Adherence, n							
Regular SPC	55	30	25	0.499	40	15	0.345
Irregular SPC	42	20	22		34	8	
Number	22.52 ± 9.16	21.80 ± 8.51	22.91 ± 9.96	0.554	20.95 ± 8.67	26.83 ± 9.65	0.007
Duration, years	10.17 ± 0.49	10.18 ± 0.50	10.17 ± 0.48	0.914	10.16 ± 0.49	10.20 ± 0.48	0.765
Mean BOP, %	16.81 ± 7.77	14.56 ± 5.28	18.16 ± 8.17	0.011	15.35 ± 6.20	19.37 ± 8.69	0.016
Mean GBI, %	5.97 ± 5.82	4.36 ± 3.30	7.13 ± 6.95	0.013	4.78 ± 4.09	8.67 ± 8.14	0.003
Mean PCR, %	31.10 ± 13.40	30.35 ± 14.45	32.23 ± 12.59	0.497	30.35 ± 14.33	34.17 ± 10.34	0.239

APT, active periodontal therapy; BOP, bleeding on probing; GBI, gingival bleeding index; MIP, molar-incisor pattern; n, number of patients; TL, overall tooth loss; PCR, plaque control record; SPC, supportive periodontal care; TLP, periodontal tooth loss.

TABLE 2 Tooth-specific characteristics

Variables	T0	T1	T2	P
Teeth				
Number of teeth (per patient)	2,360 (24.33 ± 4.04)	2,323 (23.95 ± 4.20)	2,204 (22.72 ± 5.05)	<0.0001
OTL during APT (per patient)	37 (0.38 ± 0.77)			
OTL during SPC (per patient)		119 (1.23 ± 1.74)		
TLP during SPC (per patient)		40 (0.41 ± 0.91)		
Tooth type, n/%				
Anterior	1077/45.6	1074/46.2	1050/47.6	0.002
Premolar	686/29.1	679/29.2	643/29.2	<0.0001
Molar	597/25.3	570/24.6	511/23.2	<0.0001
Periodontal bone loss, n				
0% to 20%	1180	n/a	n/a	
21% to 40%	662	n/a	n/a	
41% to 60%	276	n/a	n/a	
61% to 80%	72	n/a	n/a	
>80%	34	n/a	n/a	
Furcation involvement (FI)				
Single-rooted teeth, n	1,596	1,589	1,543	<0.0001
Multi-rooted teeth, n	764	734	661	<0.0001
Without FI, n/%	293/38.4	344/46.9	259/39.2	0.010
With FI, n/%	471/61.6	390/53.1	402/60.8	<0.0001
Degree I, n/%	256/54.3	254/64.8	283/70.4	0.620
Degree II, n/%	146/31.0	89/22.8	69/17.2	<0.0001
Degree III, n/%	69/14.7	47/12.4	50/12.4	0.004
Tooth mobility				
Without mobility, n	1777	2018	2128	<0.0001
With mobility, n	583	305	76	<0.0001
Degree I, n/%	417/71.5	251/82.3	63/82.9	<0.0001
Degree II, n/%	140/24.0	50/16.4	9/11.8	<0.0001
Degree III, n/%	26/4.5	4/1.3	4/5.3	<0.0001
Abutment status				
No abutment tooth, n	1856	1820	1679	<0.0001
Number of abutment teeth	506	503	525	0.327
Fixed, n/%	496/98.0	490/97.4	518/98.7	0.215
Removable, n/%	8/2.0	13/2.6	7/1.2	0.329
Mean PD, mm	3.16 ± 1.19	2.44 ± 0.69	2.42 ± 0.76	<0.0001
Mean CAL, mm	3.63 ± 1.52	3.12 ± 1.28	3.12 ± 1.34	<0.0001
PISA, mm^2	388.82 ± 349.47	182.38 ± 149.58	252.94 ± 187.16	<0.0001
PESA, mm^2	1,694.90 ± 457.95	1,175.35 ± 269.34	1,172.33 ± 286.73	<0.0001

APT, active periodontal therapy; CAL, clinical attachment level; FI, furcation involvement; n, number of teeth; OTL, overall tooth loss; PESA, periodontal epithelial surface area; PISA, periodontal inflamed surface area; PD, probing depth; SPC, supportive periodontal care; TLP, periodontal tooth loss.

TABLE 3 Descriptive data for PD and CAL-V according to reason for tooth loss

Variables	PD (%) ≤3 mm			PD (%) 4 to 5 mm			PD (%) ≥6 mm		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
Overall	70.0	88.0	88.5	19.9	10.5	9.6	10.1	1.5	1.9
Without OTL	74.6	91.0	89.6	18.4	8.1	8.8	7.2	0.9	1.6
With OTL	65.3	85.2	87.4	21.5	13.1	10.5	13.2	2.1	2.1
Without TLP	72.1	89.4	89.9	19.1	9.4	8.7	8.8	1.2	1.4
With TLP	63.7	83.5	84.3	22.3	14.0	12.5	14.0	2.5	3.2

Variables	CAL (%) ≤3 mm			CAL (%) 4 to 5 mm			CAL (%) ≥6 mm		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
Overall	56.8	67.6	67.7	27.5	23.6	22.9	15.7	8.9	9.4
Without OTL	62.8	74.0	70.8	26.1	20.8	22.0	11.1	5.2	7.2
With OTL	50.3	60.6	64.2	29.0	26.6	24.0	20.7	12.8	11.8
Without TLP	59.9	71.3	71.6	26.6	21.7	20.8	13.5	7.0	7.6
With TLP	46.9	55.9	55.6	30.5	29.4	29.5	22.6	14.7	14.9

Variables	GBI (%) mean ± SD		PCR (%) mean ± SD		BOP (%) mean ± SD	
	T1	T2	T1	T2	T1	T2
Overall	4.9 ± 5.5	5.1 ± 5.6	29.8 ± 17.7	32.9 ± 18.7	13.1 ± 8.9	18.1 ± 11.1
Without OTL	4.1 ± 4.3	4.5 ± 4.5	29.3 ± 17.6	28.5 ± 17.6	11.9 ± 6.8	17.5 ± 9.6
With OTL	5.9 ± 6.5	5.8 ± 6.5	30.4 ± 18.1	37.7 ± 20.2	14.4 ± 10.6	18.7 ± 12.5
Without TLP	4.1 ± 4.4	4.9 ± 4.8	29.1 ± 17.5	30.7 ± 18.5	12.5 ± 7.9	18.6 ± 11.1
With TLP	7.7 ± 7.6	5.8 ± 7.5	32.1 ± 18.7	39.7 ± 18.1	14.9 ± 11.4	16.5 ± 11.0

BOP, bleeding on probing; CAL, clinical attachment level; GBI, gingival bleeding index; OTL, overall tooth loss; PCR, plaque control record; PD, pocket probing depth; TLP, periodontal tooth loss.

TABLE 4 Tooth loss over 10 years after active periodontal therapy in relation to furcation involvement at start of supportive periodontal care

Variables	Single-rooted teeth	Multi-rooted teeth					
		Total	Without FI	With FI			
				Total	I	II	III
Total							
n	1,589	734	342	390	254	89	47
OTL, n	45	74	27	47	18	10	19
OTL, %	2.8	10.1	7.9	12.0	7.1	11.2	40.4
TLP, n	12	28	9	19	4	3	12
TLP, %	0.8	3.8	2.6	4.8	1.6	3.4	25.5

FI, furcation involvement; n, number of (lost) teeth; OTL, overall tooth loss; TLP, periodontal tooth loss.

TABLE 5 Tooth loss over 10 years after active periodontal therapy in relation to abutment status at start of supportive periodontal care

Variables	No abutment tooth	Abutment tooth		
		Total	Fixed	Removable
Total				
n	1,820	503	490	13
OTL, n	57	62	55	7
OTL, %	3.1	12.3	11.2	53.8
TLP, n	22	18	18	0
TLP, %	1.2	3.6	3.7	0.0

n, number of (lost) teeth; OTL, overall tooth loss; TLP, periodontal tooth loss.

TABLE 6 Tooth loss over 10 years after active periodontal therapy in relation to tooth mobility at start of supportive periodontal care

Variables	Teeth without mobility	Teeth with mobility			
		Total	I	II	III
Total					
n	2,018	305	251	50	4
OTL, n	67	52	30	19	3
OTL, %	3.3	17.0	12.0	38.0	75.0
TLP, n	20	20	9	8	3
TLP, %	0.1	6.6	3.6	16.0	75.0

n, number of (lost) teeth; OTL, overall tooth loss; TLP, periodontal tooth loss.

TABLE 7 Tooth loss over 10 years after active periodontal therapy in relationship to baseline periodontal bone loss

Variables	Baseline bone loss in % of root length					
	Total	≤20%	21%–40%	41%–60%	61%–80%	>80%
Total						
n	2224	1180	662	276	72	34
OTL, n	115	24	33	37	16	5
OTL, %	5.2	2.0	4.9	13.4	22.2	14.7
TLP, n	40	4	11	13	10	2
TLP, %	1.8	0.3	1.6	4.7	13.9	5.9

N, number of (lost) teeth; OTL, overall tooth loss; TLP, periodontal tooth loss.

TABLE 8 Multilevel logistic regression analysis: OTL during SPC according to different risk factors at beginning of SPC (T1)

Variables	Coefficient	SE	T	*P*	OR	95% CI for OR	
						Lower	Upper
Intercept	−5.175	0.350	−14.797	<0.001	0.006	0.003	0.011
Tooth-level							
Abutment status							
Removable	2.631	0.835	3.151	0.002	13.883	2.700	71.386
Fixed	0.678	0.229	2.962	0.003	1.970	1.258	3.086
No abutment tooth	reference						
Furcation involvement							
Degree III	0.889	0.326	2.729	0.006	2.433	1.284	4.610
Degree II	−0.023	0.340	−0.067	0.947	0.978	0.502	1.905
Degree I	0.042	0.298	0.141	0.888	1.043	0.581	1.872
Degree 0	reference						
Tooth mobility							
Degree III	1.953	1.021	1.913	0.056	7.046	0.952	52.174
Degree II	1.175	0.498	2.361	0.018	3.237	1.220	8.588
Degree I	0.712	0.225	3.157	0.002	2.037	1.309	3.169
Degree 0	reference						
Periodontal bone loss							
81%–100%	−0.268	0.602	−0.445	0.656	0.765	0.235	2.489
61%–80%	0.094	0.395	0.238	0.812	1.099	0.506	2.386
41%–60%	0.192	0.264	0.726	0.468	1.212	0.721	2.035
21%–40%	−0.077	0.189	−0.407	0.684	0.926	0.639	1.341
0%–20%	reference						
Mean CAL	0.315	0.156	2.017	0.044	1.370	1.009	1.861
Mean PD	0.303	0.098	3.094	0.002	1.354	1.118	1.642
Patient-level							
Mean BOP	0.006	0.014	0.412	0.681	1.006	0.979	1.034
Mean GBI	0.018	0.011	1.615	0.106	1.018	0.996	1.041

BOP, bleeding on probing; CAL, clinical attachment level; CI, confidence interval; GBI, gingival bleeding index; OR, odds ratio; OTL, overall tooth loss; PD, probing depth; SPC, supportive periodontal care.
Dependent variable: OTL during SPC (n=97 patients/2,186 teeth).

individually selected criteria and therefore creates a selection bias.

As in other studies,[11,12,14,22,40] only a small proportion of participants experienced OTL at all. About half of all patients (n = 47) experienced OTL and only one-quarter (n = 23) experienced TLP. Eight patients (8%; only one patient [1%] when considering TLP) in this study lost ≥5 teeth. Regardless of the reason for TL, it could be shown that most of the lost teeth were multi-rooted (OTL, 30% premolars + 50% molars; TLP, 25% premolars + 62.5% molars), which is also consistent with previous studies.[13–15,22]

Compared with other studies,[3,11,14,15,19,20,40,41] the average age at start of therapy in the present patient cohort (54.07 ± 10.90 years) was higher, yet the TL was comparable or lower. The older age depicts the currently described shift of the disease into higher age groups.[42] This general difference is probably responsible for partially different results, as shown in the following. The lower TL values probably underline the effectiveness of the applied treatment concept, which is also expressed by the reductions in PISA and PESA values, even if no comparison was made with another concept. Otherwise, greater TL would have been expected due to the high average age.[43]

With regard to the identified factors for OTL/TLP, binary logistic regression excluded variables that were often associated with TL previously due to a lack of significance. These include, in particular, smoking status,[3,20,39,44] diabetes mellitus,[6,44] adherence,[6,13,38,39,44] and initial diagnoses.[3,15,19] Initial diagnosis is determined by interproximal CAL (stages).[35] Thus, in a tooth-related analysis the patient-level factor initial diagnoses is likely to be overruled by CAL[45] because the tooth-level variable CAL

TABLE 9 Multilevel logistic regression analysis: TLP during SPC according to different risk factors at beginning of SPC (T1)

Variables	Coefficient	SE	T	P	OR	95% CI for OR	
						Lower	Upper
Intercept	−5.064	0.399	−12.661	<0.001	0.006	0.003	0.014
Tooth-level							
Abutment status							
Removable	n/a[a]						
Fixed	0.259	0.199	1.304	0.192	1.296	0.877	1.914
No abutment tooth	reference						
Furcation involvement							
Degree III	1.081	0.321	3.367	0.001	2.949	1.571	5.536
Degree II	−0.042	0.425	−0.098	0.922	0.959	0.417	2.205
Degree I	−0.236	0.220	−1.073	0.284	0.790	0.513	1.216
Degree 0	reference						
Tooth mobility							
Degree III	2.581	0.861	2.999	0.003	13.205	2.443	71.385
Degree II	0.879	0.480	1.830	0.067	2.409	0.939	6.181
Degree I	0.181	0.260	0.696	0.487	1.198	0.720	1.994
Degree 0	reference						
Periodontal bone loss							
81%–100%	−0.294	0.747	−0.394	0.694	0.745	0.172	3.227
61%–80%	0.261	0.396	0.659	0.510	1.298	0.598	2.819
41%–60%	−0.034	0.211	−0.159	0.874	0.967	0.639	1.463
21%–40%	−0.061	0.165	−0.369	0.712	0.941	0.681	1.300
0%–20%	reference						
Mean CAL	0.319	0.148	2.160	0.031	1.376	1.030	1.838
Mean PD	0.142	0.098	1.452	0.147	1.153	0.951	1.398
Patient-level							
Mean BOP	0.005	0.012	0.412	0.680	1.005	0.982	1.028
Mean GBI	0.008	0.008	0.977	0.329	1.008	0.992	1.023
Number of SPC	0.012	0.009	1.322	0.186	1.012	0.994	1.029
Grading							
C	0.084	0.146	0.577	0.564	1.088	0.817	1.450
B	reference						
A	n/a[a]						
Smoking	0.092	0.215	0.429	0.668	1.097	0.719	1.673

BOP, bleeding on probing; CAL, clinical attachment level; CI, confidence interval; GBI, gingival bleeding index; OR, odds ratio; PD, probing depth; SPC, supportive periodontal care; TLP, periodontal tooth loss.

Dependent variable: TLP during SPC (n=97 patients/2,186 teeth).

[a]This parameter was not available in at least one of the two groups.

describes the individual risk of a single tooth better than the patient-level variable initial diagnosis that provides a kind of mean score across the whole patient. Thus, in tooth-related analysis mean CAL per tooth overrules initial diagnosis. In contrast within other studies,[12,18,22] not just severe initial diagnoses were included. As result, the cohort reflects a rather moderate clinical picture. The number of patients with diabetes and active smokers was low in this study, which is why a missing correlation appears most

likely or only occurs for smoking in TLP. As already mentioned by Petsos et al.,[7] adherence was probably not identified as prognostic factor because the criteria on which it is based are very strict. Nevertheless, the importance of regular SPC should be emphasized as has been proven in numerous long-term studies.[6,20,22,38] The fact that patients who have lost teeth for periodontal reasons had on average six more SPC appointments than patients who did not have TLP shows that they were assigned a shorter

SPC interval, corresponding to a higher risk of periodontal disease.

Concerning tooth-related factors, there were similarities as well as differences with regard to OTL/TLP. In case of the abutment status, the total number of abutment teeth for RPDs was low, which may explain why no abutment tooth of an RPD was lost for periodontal reasons. It has been confirmed several times that abutment status represents a higher risk for TL compared with teeth without abutment function.[13,18,21,22] A retrospective analysis of 90 periodontally compromised patients with a mean follow-up of 9.7 years found that 3.6% of all lost teeth were abutment teeth and 2.5% of all teeth that were lost for periodontal reasons were abutment teeth.[21] The corresponding values in the present study were 2.7% (OTL) and 0.8% (TLP). The difference regarding TLP can be explained by different definition of TLP and more RPDs in the other study. The data of the present study show that the risk of losing a tooth with FPDs, both in general and for periodontal reasons, is 1.3 to 1.9 times higher than for teeth without abutment function. This risk increases seven-fold for RPDs (13.9) in case of OTL.

Initial BL was associated with a higher risk of TL in several studies,[11,13,18,22,39,44] which is underlined by its use as prognostic factor in the current framework for staging and grading periodontal diseases.[35] In the present study, neither an increased risk for OTL nor one for TLP could be shown for baseline radiographic BL. BL assessed in the same way was strongly correlated with OTL in a quite similar study;[45] however, that respective study did not consider CAL. Whereas BL only describes interproximal destruction, CAL assessed at six sites/tooth also provides information on buccal/oral destruction. Thus, CAL may have eliminated BL from the model in this analysis. Further, advanced mobility may be correlated with severe CAL and/or BL. Whereas teeth with severe CAL or BL but minor mobility are likely to be retained, advanced mobility may change the decision to extraction in teeth with severe CAL and/or BL. Only a few teeth with severe BL (>80%) were lost, which may be due to the fact that the patients behaved more adherently with increasing BL (see Supplementary Fig. S1 in online *Journal of Periodontology*).

Unlike other studies,[11,13,18,22] this study did not only distinguish between single- and multi-rooted teeth but also between multi-rooted teeth according to their maximum FI. While no correlation with FI was found for degrees I and II, such was confirmed for FI III for OTL as well as TLP.[15] Although teeth with FI III showed the lowest PISA values (169.5 mm^2) as compared with teeth with FI I (201.6 mm^2) and II (184.7 mm^2), accessibility for cleaning may be a decisive factor. A positive correlation between an FI II and TLP would be expected. This may have been prevented by consistent therapy of furcations with FI II during APT,

which led to a reduced number of class II furcations (T0: n = 146; 31.0% versus T1: n = 89; 22.8%). Martinez-Canut et al. also differentiated according to FI and showed—with a significantly larger cohort—more conclusive correlations (FI I, $P = 0.120$; FI II, $P = 0.001$; FI III, $P = 0.002$).[15] However, they only evaluated molars, excluding maxillary premolars. In the present investigation, a total of 88% of all furcation-involved teeth at T1 were retained for 10 years. Looking at TLP, the survival rate of these teeth increased to 95%. Even for FI III, the survival rates were 59.6% (OTL) and 74.5% (TLP) over 10 years. This confirms other authors' findings who have reported survival rates of molars with FI III of 70% to 76.5% over 5 to 20 years.[13,46] Overall, survival rate decreases within the oral cavity from anteriors (97.8%) to premolars (94.7%) to molars (89.6%), which agrees with previous studies.[11,13]

Tooth mobility is associated with a significantly increased risk of TLP for degree III. This relationship is different with OTL, where it is significant for mobility degrees I and II but there is only a trend with degree III ($P = 0.056$). This is probably due to the fact that most teeth with mobility degree III were removed for periodontal reasons, whereas the remaining teeth with mobility degree I or II were accompanied by further diagnoses that led to extractions. Mobility degrees are usually viewed in a summarized manner, similar to FI, and have been confirmed as a predictor for OTL in a systematic review.[44] Teeth already splinted during APT (T0-T1) may cause bias.

Significant positive associations between CAL (lost teeth, 4.9 ± 1.9 mm; retained teeth, 3.0 ± 1.2 mm) and between PD (lost teeth, 3.2 ± 1.1 mm; retained teeth, 2.4 ± 0.6 mm) and OTL were found, which occurred for TLP only with CAL (lost teeth, 5.8 ± 2.0 mm; retained teeth, 3.1 ± 1.2 mm). It is well known that increased PD after completion of APT increases the risk of TL.[11,15,47] This underlines the importance of regular re-evaluation and re-instrumentation of residual PD. The lack of correlation between TLP and PD in the present study possibly shows the effectiveness of the applied treatment concept. Although CAL in this cohort is not as pronounced as in other studies that included more severe initial diagnoses, a correlation with OTL and TLP could be shown. While the average CAL for TLP is about 1.0 mm higher than that for OTL, the correlation with OTL may be explained by the fact that greater attachment loss occurred in addition to the primary reasons for extraction (e.g., endodontic–periodontal lesions, root surface caries), since a single loss of attachment would primarily have led to extraction for periodontal reasons.

Most of the prognostic factors for OTL/TLP identified here have already been reported previously.[11–15,18,22,38,39,48] Nevertheless, repeated identification using another cohort is important with respect to general applicability. Looking

at single factors, their clinical relevance remains questionable regarding the annual TL rate of 0.12 teeth/patient. However, considering that the risk of losing teeth accumulates when several factors occur at the same time, it makes sense to take these into account for treatment planning. In general, extraction decisions should be weighed against the background of extensive prosthetic rehabilitation and the associated costs and effort.[11,49]

This study has limitations, which should be addressed self-critically. First, as compared with in other studies, which report 48% to 75% of lost teeth to be lost for periodontal reasons,[15,40,41,48] this study reports a value of 34%. However, the definition and assignment of criteria for extraction is difficult and, in part, subjective. Second, data collection at T0/T1 and the primary outcome partly depended on the involvement of differently experienced, non-calibrated practitioners and their decisions, including in some cases even from outside the center. Third, TL will still be underestimated, as the retrospective study design could not ensure that invited patients who had completely discontinued SPC were also followed up with. Fourth, despite adjustment of multilevel regression models, statistical interaction effects may have influenced the results to a relevant extent. Due to these limitations, the results of this study can only partially be generalized. However, the patient-cohort depicts a practice-relevant composition in which both adherent and non-adherent, older patients with different general diseases and smoking habits were represented.

5 | CONCLUSIONS

Within the limitations of this study the following conclusions can be drawn: (1) Only one-third of all lost teeth were lost for periodontal reasons—according to the definition chosen for TLP—which underlines the efficacy of the applied periodontal concept. (2) Use as abutment tooth, FI III, tooth mobility degrees I and II, mean CAL, and PD were identified as prognostic factors for OTL. FI, mobility degree III, and mean CAL positively correlated with TLP. (3) Teeth with initially severe BL are not hopeless. Comprehensively treated they can be retained over extended periods of. Thus, premature extraction should be avoided. (4) Prosthetic replacement of prematurely removed teeth may involve other periodontally compromised teeth as abutment teeth, which may jeopardize their long-term retention.

AUTHOR CONTRIBUTIONS

All authors contributed substantially to the interpretation of the data for the work; they contributed to drafting and critically revising the article, they gave their final approval of the version to be published and agree to be accountable for all aspects of the work. Additionally, Peter Eickholz and Bettina Dannewitz conceived the ideas; Hari Petsos, Tatjana Ramich, Katrin Nickles, Peter Eickholz collected the data; Leon Pfeifer and Otto Zuhr contributed to data analysis and interpretation; Leon Pfeifer and Otto Zuhr complied methodical approaches and contributed to data interpretation; Hari Petsos analyzed data; and Peter Eickholz and Hari Petsos led the writing.

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SUPPORTING INFORMATION

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

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