

The impact of a “successfully treated stable periodontitis patient status” on patient-related outcome parameters during long-term supportive periodontal care

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Abstract

Aim: To assess the importance of achieving a successfully treated stable periodontitis patient status (PPS) during long-term supportive periodontal care (SPC).

Materials and Methods: This retrospective cohort study included 100 periodontitis patients, who continued for ≥ 7.5 years after active periodontal treatment with SPC and were judged as overall adherent. The effect of various predictors on three patient-related outcome parameters was assessed: (1) number of diseased teeth at last SPC, (2) number of teeth lost due to periodontitis, and (3) number of teeth lost due to any reason.

Results: One-fifth of the patients were classified as stable after active periodontal treatment. After a mean follow-up of 10.77 years, 24 patients lost 38 teeth due to periodontitis. An unstable PPS and a higher number of diseased teeth per patient at first SPC, and inadequate oral hygiene levels over time, significantly increased the risk for a higher number of diseased teeth per patient at last SPC and for more lost teeth due to periodontitis. However, high adherence to SPC appeared to mitigate the negative effect of an unstable PPS, especially regarding tooth loss due to periodontitis. Further, tooth loss due to any reason was about 3 times higher than tooth loss due to periodontitis and was affected by a larger number of predictors.

Conclusions: Successfully treated patients with a stable PPS maintained a small number of diseased teeth and barely lost any teeth during long-term SPC compared to patients who did not achieve a stable PPS after active periodontal therapy.

KEYWORDS

adherence, classification, periodontitis, supportive periodontal care, tooth loss

Clinical Relevance

Scientific rationale for study: There is no information on the possible long-term impact of achieving a stable periodontitis patient status (PPS) after active periodontal therapy.

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Principal findings: About 80% of the patients failed to achieve a stable PPS. This increased their risk for a higher number of diseased and lost teeth during supportive periodontal care (SPC). Only one out of 38 teeth lost due to periodontitis was in a patient with stable PPS. However, tooth loss due to periodontitis was in general rare and regarded a small fraction of the population.

Practical implications: Achieving a stable PPS is associated with a better prognosis after long-term SPC, while high adherence appears to balance a less than optimal result after active treatment.

1 | INTRODUCTION

The 2018 classification of periodontal and peri-implant diseases and conditions introduced a new staging and grading system of periodontitis (Tonetti et al., 2018), reflecting disease severity and susceptibility to disease. Indeed, it was recently shown that patients classified as stage 4 and/or grade C undergoing supportive periodontal care (SPC) present a significantly higher risk for tooth loss due to periodontitis (Ravidà et al., 2020). However, the classification also included a definition for a successfully treated stable periodontitis patient (Chapple et al., 2018), that is, a patient after active periodontal treatment with a clinically stable and inflammation-free, but due to previous disease activity, reduced periodontium. More specifically, such a patient is characterized by presenting (1) all sites with a probing pocket depth (PD) ≤ 4 mm, (2) no site with PD = 4 mm with bleeding on probing (BoP), (3) full-mouth BoP $< 10\%$, and (4) with radiological bone and clinical attachment loss. Currently there is only limited information about the impact on tooth loss and/or disease progression on the long term, if such an optimal treatment outcome can be achieved. Nevertheless, such a strict definition probably requires patients, who are interested in and willing to receive continuous SPC, to maintain the outcome on the long term. It is well known that low adherence (compliance) in terms of attending regular SPC leads to deterioration of the periodontal status and increased tooth loss over time (Lee et al., 2015). Therefore, the present study aimed to assess the possible effect of achieving a stable periodontitis patient status (PPS) after active periodontal treatment on disease status and progression using number of diseased teeth and tooth loss as surrogates during long-term SPC in a sample of overall adherent patients.

2 | MATERIALS AND METHODS

2.1 | Patient population and eligibility criteria

This retrospective cohort study is based on patients who were treated at the Division of Conservative Dentistry and Periodontology at the University Clinic of Dentistry, Medical University of Vienna, Austria. The study protocol was approved by the local Ethics Committee (EK-Nr. 1010/2017) and followed the “Strengthening the Reporting of Observational studies in Epidemiology” checklist (Appendix S1). All patients receiving SPC for the first time after active periodontal treatment from

2002 to 2006 and continuing to receive SPC until 2012 to 2016 were checked for eligibility ($n = 237$). Only patients with complete anamnestic, clinical, and radiographic records, classified as periodontitis stage 3 or 4 (Tonetti et al., 2018), and a moderate to high adherence rate for at least 7.5 years were included in the present study.

2.2 | Judgement of adherence rate

Based on the periodontal risk assessment at baseline, frequency of SPC need was judged for each patient as once, twice, or three to four times per year. Number of SPC appointments required was compared to the attended number of SPC appointments per year during follow-up. Patient's adherence was classified as “highly adherent”, “moderately adherent”, or “non-adherent”. Specifically, a patient was judged as “highly adherent” if the defined number of required appointments was attended in each year during follow-up; as “moderately adherent” if in at least two-thirds of all years during follow-up the defined number of required appointments were attended (e.g., in at least 6 out of 9 years of SPC, but there was only maximum 1 year in a row where the defined number of required appointments was not attended), and as “non-adherent” otherwise. Further, if a patient did not receive SPC for more than 24 months, the patient was directly judged as “non-adherent”.

2.3 | Parameters recorded at first SPC (baseline)

The first SPC appointment (i.e., the first appointment after finishing active periodontal treatment including non-surgical and surgical periodontal treatment according to the patients' needs) was defined as baseline. Based on data from the patients' dental records (i.e., number of teeth per patient and the periodontal status registering PD and BoP at six sites per tooth with a CP-12 periodontal probe with markings at 3, 6, 9, and 12 mm; both without third molars), including patients' characteristics and their medical history [i.e., age, gender, presence/absence of diabetes mellitus, and smoking status (non-smoking/smoking)], the following patient-related parameters were defined and recorded at baseline:

- Periodontal risk assessment (Lang & Tonetti, 2003):
 - (1) Low, (2) moderate, or (3) high risk for disease progression.
- Grading of periodontal disease (Tonetti et al., 2018):

- Percentage of bone loss measured in panoramic radiographs in a dedicated image analysis program (Sidexis XG; Sirona Dental Systems, Bensheim, Germany) was divided by age resulting in (1) <0.25 (grade A), (2) 0.25–1 (grade B), or (3) >1 (grade C).
- PPS (Chapple et al., 2018):
 - “Stable” defined as (1) all sites of the patient present PD ≤ 4 mm, (2) no site with PD = 4 mm with BoP, and (3) full-mouth BoP <10%.
 - “Unstable” if not meeting above-mentioned criteria for classification as “stable”.
- Number of diseased teeth per patient (Chapple et al., 2018):
 - “Non-diseased” tooth defined as (1) all sites of the tooth present PD ≤ 4 mm, and (2) no site with PD = 4 mm with BoP.
 - “Diseased” tooth if not meeting above-mentioned criteria for classification as “non-diseased”.

2.4 | Parameters recorded until last SPC

The last available SPC in the records was defined as the final evaluation. The following parameters were extracted/calculated from data from the patients' records:

- Follow-up period in years from baseline to last SPC.
- Level of oral hygiene, assessed by the approximal plaque index in percent (API; all plaque positive inter-proximal spaces after staining divided by all assessed inter-proximal spaces multiplied by 100) (Lange et al., 1977) and the simplified papilla bleeding index in percent (PBI; all inter-proximal spaces positive for bleeding after following the inter-proximal sulcus mesial and distal with a periodontal probe divided by all assessed interproximal spaces multiplied by 100) (Saxer & Mühlemann, 1975); API and PBI were extracted at three time points (i.e., at first SPC, approximately after 5 years, and at last SPC).
 - “Good level”, defined as API or PBI below 30% or 20%, respectively, at all three time points.
 - “Average level”, defined as maximum one out of three time points presenting with an API or PBI $\geq 30\%$ or 20%, respectively.
 - “Poor level”, if not meeting the above-mentioned criteria for classification as “good” or “average”.
- PPS at last SPC.
- Number of diseased teeth per patient at last SPC.
- Number of teeth lost due to periodontitis (i.e., ongoing/uncontrolled periodontal inflammation, increased mobility, deepened PD, continuous attachment loss, etc.) or due to any reason (i.e., periodontal, endodontic or restorative problems, tooth fracture, prosthetic reasons, orthodontic treatment plan, unknown) until last SPC.

3 | STATISTICAL ANALYSIS

Data at baseline and at last SPC were summarized descriptively and compared between the highly and moderately adherent population.

A Chi-squared test was applied for categorical parameters and for continuous variables either the independent *t*-test (for normally distributed data) or the Mann–Whitney *U*-test (for data lacking normal distribution) was applied; distribution of the data was controlled by the Shapiro–Wilk test. Three patient-related parameters were defined as primary outcome parameters: (1) number of diseased teeth per patient at last SPC, (2) number of teeth lost due to periodontitis until last SPC, and (3) number of teeth lost due to any reason until last SPC. The following patient-related parameters were used as predictors: (1) age, (2) gender, (3) follow-up period, (4) diabetes mellitus, (5) smoking status, (6) grading, (7) API level, (8) PBI level, (9) PPS at baseline, and (10) number of diseased teeth per patient at baseline. In a first step, a univariate analysis (negative binominal regression) was performed with all predictors separately for all three outcome parameters. Thereafter, a multivariate analysis was performed; specifically, a stepwise negative binominal regression analysis starting with the full model and defining a *p*-value of .2 as criterion for the stepwise exclusion was applied. The multivariate analysis was performed twice for all three primary outcome parameters, that is, once for all included patients, and once only for the highly adherent patients. The intention of the latter sub-analysis was to assess whether a “perfect” adherence can change the effect of any relevant predictors reported in an overall adherent population. As patients contributed with different follow-up periods, which might affect the likelihood of tooth loss (e.g., tooth loss might be more likely to occur after 13 years compared to 7.5 years), both analyses (i.e., univariate and multivariate) for both primary outcome parameters on tooth loss were corrected for the follow-up period (i.e., follow-up time was used as offset in the negative binominal regression). This correction was not applied for the other primary outcome parameter (number of diseased teeth per patient at last SPC), as this parameter represents the data at a specific time point (i.e., at last SPC) and not cumulative data. Statistical analysis was performed with STATA/IC 16.0 for Mac, and a *p*-value of $\leq .05$ was considered as statistically significant. The impact of various predictors on tooth-related outcome parameters in this population will be reported elsewhere.

4 | RESULTS

4.1 | Patient population at baseline

Out of the original 237 patients, 100 patients (50.52 years of age; 44 females; 2257 teeth; on average 22.57 teeth per patient) fulfilled the eligibility criteria and were included in the study. The patient population included four patients with diabetes mellitus and 23 smokers. Patients were either classified as grade B (54%) or grade C (46%), but none as grade A. Seventy patients presented a moderate risk for disease progression at baseline and were accordingly scheduled twice per year for SPC. Only 21 patients met all criteria for a successfully treated stable PPS after active periodontal treatment. About 2.41 teeth per patient were still considered as diseased after active periodontal treatment with a range of 0–14

TABLE 1 Patient characteristics at first SPC (i.e., at baseline)

Parameter		All patients (n = 100)	Highly adherent patients (n = 63)	Moderately adherent patients (n = 37)	p-Value
Age (years)	Mean ± SD	50.52 ± 10.50	49.39 ± 10.63	52.46 ± 10.12	.159 ^a
	Median (Q1; Q3)	49.89 (42.51; 59.35)	48.54 (41.85; 57.41)	53.34 (43.11; 60.28)	
	Range	18.50–69.21	18.50–69.20	34.09–68.04	
Gender	Female/male	44/56	27/36	17/20	.764
Diabetes mellitus	Present/absent	4/96	4/59	0/37	.118
Smoking status	Smoking/non-smoking	23/77	14/49	9/28	.809
Number of teeth	Mean ± SD	22.57 ± 4.97	23.57 ± 4.24	20.87 ± 5.67	.020^b
	Median (Q1; Q3)	24 (20; 26)	25 (22; 27)	21 (18; 26)	
	Range	5–28	5–28	7–28	
Periodontal risk assessment	Low/moderate/high	23/70/7	20/43/0	3/27/7	< .001
Grading	<0.25/0.25–1/>1	0/54/46	0/34/29	0/20/17	.993
PPS	Stable/unstable	21/79	9/54	12/25	.031
Number of diseased teeth per patient	0/1–4/≥5 teeth	27/58/15	13/38/12	14/20/3	.067^b
	Range	0–14	0–10	0–14	
	Mean ± SD	2.41 ± 2.56	2.64 ± 2.38	2.03 ± 2.82	
	Median (Q1; Q3)	2 (0; 4)	2 (1; 4)	1 (0; 3)	

Note: Bold values indicate statistical significance.

Abbreviations: PPS, periodontitis patient status; Q1/Q3, first/third quartile; SD, standard deviation; SPC, supportive periodontal care.

^ap-Value relates to the mean values and independent t-test was applied.

^bp-Value relates to the median values and Mann–Whitney U-test was applied.

teeth per patient, but only 15 patients presented ≥5 diseased teeth. The comparison between the highly and moderately adherent patients displayed a significantly lower number of teeth, higher number of patients with high risk for disease progression, and higher number of patients with a stable PPS among the moderately adherent patients. The patients' characteristics at baseline are summarized in Table 1.

4.2 | Patient population until last SPC

Patients were followed for a mean period of 10.77 years (range 7.54–13.19 years), with 63 patients being highly adherent. Most of the patients (i.e., > 80%) presented average or good levels of oral hygiene. The number of diseased teeth per patient increased, compared to baseline, by one tooth to 3.41 (range 0–18 teeth per patient). Twenty-nine patients presented ≥5 diseased teeth (i.e., the number of patients almost doubled compared to baseline), while 17 patients presented a stable PPS. Further, 76 patients did not lose a single tooth due to periodontitis, while 24 patients lost altogether 38 teeth (range 1–4 teeth per patient), resulting, on average, in a tooth loss rate due to periodontitis of 0.38 per patient, corresponding to 0.035 teeth per patient per year. Except for a single patient losing a single tooth, all patients losing teeth due to periodontitis had an

unstable PPS at baseline. The tooth loss rate was 3 times higher if all causes for tooth loss were considered, that is, 56 patients lost 117 teeth (range 1–12 teeth per patient), while 44 patients did not lose a single tooth, resulting, on average, in a tooth loss rate due to any reason of 1.17 per patient, corresponding to 0.109 teeth per patient and year. Detailed reasons for tooth loss are listed in Appendix S2. At the last SPC, the moderately adherent patients displayed a significantly lower number of diseased teeth per patient. The patients' characteristics until last SPC are summarized in Table 2.

4.3 | Univariate analyses

The results of the univariate analyses are summarized in Appendixes S3a–c.

4.4 | Multivariate analyses

4.4.1 | Predictors affecting the number of diseased teeth per patient at last SPC

PPS and the number of diseased teeth per patient at baseline presented a significant effect. Specifically, an unstable PPS increased

TABLE 2 Patient characteristics until last SPC

Parameter		All patients (n = 100)	Highly adherent patients (n = 63)	Moderately adherent patients (n = 37)	p-Value
Follow-up period (years)	Mean ± SD	10.77 ± 1.38	10.76 ± 1.34	10.77 ± 1.46	.993 ^a
	Median (Q1; Q3)	10.74 (9.84; 12.01)	10.72 (9.81; 11.97)	10.74 (9.86; 12.04)	
	Range	7.54–13.19	7.61–12.83	7.54–13.19	
API level	Good/average/poor	43/40/17	29/22/12	14/18/5	.390
PBI level	Good/average/poor	85/14/1	55/7/1	30/7/0	.426
PPS at last SPC	Stable/unstable	17/83	8/55	9/28	.135
Number of diseased teeth per patient at last SPC	0/1–4/≥5 teeth	27/44/29	12/28/23	15/16/6	.001^b
	Range	0–18	0–18	0–15	
	Mean ± SD	3.41 ± 3.72	4.14 ± 3.65	2.16 ± 3.53	
	Median (Q1; Q3)	3 (0; 5)	3 (1; 6)	1 (0; 2)	
Number of teeth lost due to periodontitis per patient	0/1/2/3/4	76/16/4/2/2	47/11/3/1/1	29/5/1/1/1	.716 ^b
	Range	0–4	0–4	0–4	
	Mean ± SD	0.38 ± 0.83	0.38 ± 0.79	0.38 ± 0.89	
	Median (Q1; Q3)	0 (0; 0)	0 (0; 1)	0 (0; 0)	
Number of teeth lost due to any reason per patient	0/1/2/3/≥4	44/31/11/5/9	29/21/7/2/4	15/10/4/3/5	.276 ^b
	Range	0–12	0–6	0–12	
	Mean ± SD	1.17 ± 1.75	0.94 ± 1.24	1.57 ± 2.35	
	Median (Q1; Q3)	1 (0; 1.5)	1 (0; 1)	1 (0; 2)	

Note: Bold values indicate statistical significance.

Abbreviations: API, approximal plaque index; PBI, papilla bleeding index; PPS, periodontitis patient status; Q1/Q3, first/third quartile; SD, standard deviation; SPC, supportive periodontal care.

^ap-Value relates to the mean values and independent t-test was applied.

^bp-Value relates to the median values and Mann-Whitney U-test was applied.

TABLE 3 Multivariate analysis (negative binominal regression) for the primary outcome parameter “number of diseased teeth per patient at last SPC” in all patients and in the highly adherent patients only

Predictor	IRR	95% CI		p-Value	
		Lower	Upper		
All patients (n = 100)					
PPS at baseline	Stable				
	Unstable	1.917	1.005	3.655	.048
Number of diseased teeth per patient at baseline	Count	1.100	1.008	1.202	.033
Highly adherent patients (n = 63)					
API level	Good				
	Average	1.399	0.884	2.214	.152
	Poor	–	–	–	–
Number of diseased teeth per patient at baseline	Count	1.084	0.992	1.185	.074

Note: Statistically significant p-values are indicated in bold. All variables considered for the analysis are presented in the univariate analysis (Appendix S3a). Abbreviations: API, approximal plaque index; CI, confidence interval; IRR, incidence ratio rate; PPS, periodontitis patient status; SPC, supportive periodontal care.

the risk for an additional diseased tooth at last SPC 1.9 times, and each additional diseased tooth at baseline increased the risk for an additional diseased tooth at last SPC by 10%. Considering only the highly adherent patients, none of the tested predictors remained statistically significant (Table 3).

4.4.2 | Predictors affecting the number of teeth lost due to periodontitis

API level and PPS at baseline presented a significant effect. Specifically, poor oral hygiene over time increased the risk for

Predictor	IRR	95% CI		p-Value
		Lower	Upper	
All patients (n = 100)				
API level	Good	-	-	-
	Average	-	-	-
	Poor	9.057	1.885	43.516
PPS at baseline	Stable	-	-	-
	Unstable	86.897	7.084	1066.023
Highly adherent patients (n = 63)				
API level	Good	-	-	-
	Average	-	-	-
	Poor	12.870	1.539	107.627

Note: Statistically significant *p*-values are indicated in bold. All variables considered for the analysis are presented in the univariate analysis (Appendix S3b).

Abbreviations: API, approximal plaque index; CI, confidence interval; IRR, incidence ratio rate; PPS, periodontitis patient status.

TABLE 4 Multivariate analysis (negative binominal regression) for the primary outcome parameter “number of teeth lost due to periodontitis per patient” in all patients and in the highly adherent patients only; analysis was corrected for the period of follow-up

Predictor	IRR	95% CI		p-Value	
		Lower	Upper		
All patients (n = 100)					
Age	Years	1.071	1.029	1.116	.001
Gender	Female	-	-	-	-
	Male	1.881	0.796	4.444	.150
Smoking status	Non-smoking	-	-	-	-
	Smoking	2.287	0.890	5.874	.086
API level	Good	-	-	-	-
	Average	-	-	-	-
	Poor	3.820	0.959	15.217	.057
PBI level ^a	Good	-	-	-	-
	Average/poor	2.579	0.653	10.180	.176
PPS at baseline	Stable	-	-	-	-
	Unstable	12.040	3.818	37.968	<.001
Highly adherent patients (n = 63)					
Age	Years	1.102	1.035	1.173	.003
Gender	Female	-	-	-	-
	Male	3.111	1.018	9.512	.047
Diabetes mellitus	Absent	-	-	-	-
	Present	0.197	0.027	1.453	.111
PBI level ^a	Good	-	-	-	-
	Average/poor	10.015	2.240	44.777	.003
PPS at baseline	Stable	-	-	-	-
	Unstable	5.956	1.129	31.414	.035

Note: Statistically significant *p*-values are indicated in bold. All variables considered for the analysis are presented in the univariate analysis (Appendix S3c).

Abbreviations: API, approximal plaque index; CI, confidence interval; IRR, incidence ratio rate; PPS, periodontitis patient status.

^aAverage and poor was pooled, as only one patient was present in the “poor” category.

TABLE 5 Multivariate analysis (negative binominal regression) for the primary outcome parameter “number of teeth lost due to any reason per patient” in all patients and in the highly adherent patients only; analysis was corrected for the period of follow-up

tooth loss due to periodontitis 9 times and an unstable PPS at baseline increased the risk for tooth loss due to periodontitis 87 times. Considering only the highly adherent patients, the API level remained statistically significant, but not PPS, that is, an unstable PPS at baseline did not increase the risk for tooth loss due to periodontitis among highly adherent patients (Table 4).

4.4.3 | Predictors affecting the number of teeth lost due to any reason

Age and PPS at baseline presented a significant effect. Specifically, each year increased the risk for tooth loss due to any reason by 7%, and an unstable PPS at baseline increased the risk for tooth loss due to any reason about 12 times. Considering only the highly adherent patients, four predictors (i.e., age, gender, PBI level, and PPS at baseline) reached statistical significance. Specifically, each year increased the risk for tooth loss due to any reason by 10%, and males had a 3 times higher risk to suffer tooth loss due to any reason. Further, an average/poor PBI level and an unstable PPS at baseline increased the risk for tooth loss due to any reason 10 and 6 times, respectively (Table 5).

5 | DISCUSSION

Prevention of disease recurrence, which might later ultimately lead to tooth loss, is the main aim of periodontal therapy. The present study follows a series of periodontal long-term cohort studies proving the success of periodontal treatment, in general, and specifically of SPC (Hirschfeld & Wasserman, 1978; Lindhe & Nyman, 1984; Demetriou et al., 1995; Tonetti et al., 1998; König et al., 2001; Rosling et al., 2001; König et al., 2002; Eickholz et al., 2008; Matuliene et al., 2008; Pretzl et al., 2008, 2016, 2018; Müller et al., 2013; Salvi et al., 2014; Graetz et al., 2015; Dannewitz et al., 2016; Díaz-Faes et al., 2016; Graetz, Plaumann, et al., 2017; Graetz, Sälzer, et al., 2017; Müller Campanile et al., 2019; Petsos et al., 2020; Rahim-Wöstefeld et al., 2020). Here, a population of 100 stage 3 or 4 periodontitis patients with a moderate to high adherence was evaluated 7.5–13 years after finishing active periodontal treatment. On average, less than 0.5 tooth per patient was lost over the entire follow-up period due to periodontitis; three out of four patients did not lose any teeth, and only a very small fraction lost up to four teeth. These numbers of tooth loss due to periodontitis are in good agreement with previous long-term studies and confirm that tooth loss primarily occurs in a small fraction of the population (Hirschfeld & Wasserman, 1978; Tonetti et al., 2000; Checchi et al., 2002; König et al., 2002; Eickholz et al., 2008; Ng et al., 2011; Dannewitz et al., 2016; Graetz, Plaumann, et al., 2017; Nibali et al., 2017; Pretzl et al., 2018; Bäumer et al., 2020; Petsos et al., 2020).

In this context, the present study focused on the effect of a newly defined stable PPS after active periodontal treatment (Chapple et al., 2018) on the long-term outcome. At the end of active periodontal treatment (i.e., beginning of SPC), only one out of five patients was

classified as successfully treated stable periodontitis patient, and another six patients presented only non-diseased teeth (i.e., all pockets were considered as closed) but their full-mouth BoP exceeded 10%. This indicates that it may be difficult to achieve such an optimal result in stage 3 and 4 periodontitis patients. On the other hand, only 15 patients presented five or more diseased teeth, and the majority (i.e., almost 60% of the patients) failed to be classified as stable only due to one to four diseased teeth. Nevertheless, although only a smaller fraction of the patients in the present sample was considered as successfully treated, multivariate analysis showed a stable PPS as a significant predictor for all outcome variables tested. Specifically, cases defined as stable at baseline presented a significantly lower number of diseased teeth at last SPC even when accounting for the number of diseased teeth at baseline; moreover, each additional diseased tooth per patient at baseline increased the risk of having a higher number of diseased teeth per patient at last SPC by 10%. Further, being classified as unstable at the beginning of SPC was also a risk factor for tooth loss due to periodontitis, that is, except for a single patient losing a single tooth, all patients losing teeth due to periodontitis had an unstable PPS at baseline. This resulted in multivariate analysis in an incidence ratio rate (IRR) of almost 87 for an increased number of teeth lost due periodontitis if the definition of a successfully treated stable PPS was not met at baseline. However, because of the limited number of patients and lost teeth due to periodontitis (i.e., 38 teeth in 100 patients), these results must be taken with care, which is also reflected in the large 95% confidence interval (Table 4). Hence, future studies, including a larger number of patients and thereby likely a larger number of lost teeth due to periodontitis, are warranted to confirm these results. Nevertheless, such an increased risk for an inferior long-term outcome (i.e., recurrence/progression of disease, tooth loss) due to non-closed pockets after active periodontal treatment is in agreement with previous reports (Matuliene et al., 2008; Salvi et al., 2014; Graetz et al., 2015; Dannewitz et al., 2016; Dopico et al., 2016; Graetz, Plaumann, et al., 2017; Graetz, Sälzer, et al., 2017; Ramseier et al., 2019; Costa et al., 2020). For example, PD ≥ 6 mm and BoP in more than 30% of the sites have been reported as risk factors (Matuliene et al., 2008; Ramseier et al., 2019). Further, Ramseier et al. (2019) reported that a larger number of sites with PD ≥ 4 mm and with BoP was associated with less reduction in residual PD between two consecutive SPC visits. In the present sample, at the end of the follow-up, 27% of the patients presented all teeth with closed pockets, but the number of patients presenting five or more diseased teeth doubled during long-term SPC. Such a treatment outcome including a slight deterioration over time is in line with previously published data (Matuliene et al., 2008) in a comparable population. Particularly in an overall adherent patient population receiving SPC at a university setting, the percentage of patients with no PD ≥ 5 mm dropped from 28% to 18%, and patients with more than five residual PD ≥ 5 mm increased by approximately 10%, within a timeframe of 11 years. Altogether, it appears difficult to achieve a stable PPS after active periodontal treatment, and clinicians should be aware of its apparent significant effect on the long-term outcome of SPC. It seems reasonable to require high SPC adherence

from such patients and potentially alter (increase) SPC frequency. Nevertheless, to what extent the SPC schedule should be altered if the definition of a successfully treated stable PPS is not met after active therapy should be addressed in future studies.

It was interesting to see that perfect adherence during SPC appeared to successfully compensate for a less than optimal result after active periodontal treatment, especially in terms of tooth loss due to periodontitis. The negative effect of not achieving a stable PPS at baseline disappeared when evaluating only the highly adherent patients. Similar conclusions have been drawn previously (Matuliene et al., 2010), that is, full adherence with SPC may compensate for a patient's higher risk for disease recurrence. In this context, there is a lack of consensus regarding the definition of adherence for SPC (Amerio et al., 2020). Specifically, most studies assessing the long-term outcome of SPC apply slightly different definitions, which is partly due to the dependence on the available data, as most of the studies are retrospective. For instance, definitions range from a pure mean number of SPC appointments over the follow-up period to more sophisticated approaches considering a maximum time interval between each single SPC appointment. Here, it was attempted to judge the need/frequency of SPC based on a suggested periodontal risk assessment tool (Lang & Tonetti, 2003) and taking each single year and any discontinuation during the follow-up into account. Altogether, methods and measures to achieve a high adherence should be incorporated as much as possible in the clinical routine.

The patients' plaque level over time was depicted here as another significant parameter for the long-term outcome. Poor plaque control over time increased the risk for tooth loss due to periodontitis 9 times. Interestingly, this risk due to poor plaque control over time was even higher among the highly adherent patient population (IRR: 12.8), that is, even if the patients were adhering to the scheduled SPC appointments, insufficient oral hygiene over time significantly increased the risk for tooth loss due to periodontitis. Plaque control had been described previously as a relevant risk factor (Eickholz et al., 2008; Pretzl et al., 2008; Dopico et al., 2016), although not consistently (Ramfjord et al., 1982; Checchi et al., 2002; Dannewitz et al., 2016; Nibali et al., 2017). The controversy might originate on the judgement of plaque control, that is, whether a single value at the beginning and/or end of SPC was considered, or whether several values during SPC were considered. Other included predictors, such as grading according to the 2018 classification (Tonetti et al., 2018), smoking, diabetes, gender, age, and so on, were not significant here. Especially, smoking not having a significant impact on stability is not in agreement with the majority of the existing literature (König et al., 2002; Papantonopoulos, 2004; Rieder et al., 2004; Eickholz et al., 2008; Matuliene et al., 2008; Salvi et al., 2014; Dannewitz et al., 2016; Díaz-Faes et al., 2016; Costa & Cota, 2019). This might at least partly depend on the number of smokers included, on the lack of updating the smoking status over time, and on the lack of data on the number of cigarettes smoked per day. Finally, a separate statistical analysis was performed with either tooth loss due to periodontitis or tooth loss due to any

reason as the primary outcome parameter. As tooth loss due to any reason naturally includes tooth loss due to periodontitis, one might expect similar predictors to be relevant. However, based on the present data different predictors were identified as statistically relevant, respectively the IRR of the significant predictors was clearly altered. These differences based on the type of tooth loss also explain—at least partly—any differences (e.g., the lack of age as significant predictor) compared to previous studies (Eickholz et al., 2008; Dannewitz et al., 2016). Hence, if possible, future studies should analyse tooth loss due to periodontitis and due to any reason separately.

Here, the aim was to assess the importance of achieving a successfully treated stable PPS during long-term SPC, and—although it can be considered as a limitation of the present study—not to assess which treatment modality may more predictably result in a stable PPS. Indeed, it has been shown that specific interventions may provide clinical and/or histological benefits of different magnitude and type at different defect morphologies and thus influence PPS after the active treatment phase. For example, regenerative periodontal surgery may result in larger clinical improvements and more frequent pocket closure in deep intrabony defects compared with conventional surgery (Stavropoulos et al., 2003, 2021). However, the type of histological outcome after treatment, that is, mainly regeneration versus mainly repair, appears not to influence the risk of disease recurrence, which mainly depends on the adherence to SPC (Cortellini et al., 1996; Kostopoulos & Karring, 2004). In this context, the possible impact of different treatment modalities during the active treatment phase, that is, non-surgical, surgical, resective, regenerative, and/or local/systemic antibiotic therapy, on the long-term outcome in overall adherent patients seems interesting to address in future studies.

In conclusion, based on a population of 100 stage 3 or 4 periodontitis patients with a moderate to high adherence and an average SPC period of 11 years, the following can be concluded:

1. Patients failing to achieve a stable PPS after active periodontal treatment present a statistically significantly higher risk for an increased number of diseased teeth and tooth loss in the long term.
2. Tooth loss due to periodontitis is a rare event during SPC (0.035 teeth/patient/year) and occurs only in a small fraction of the population (i.e., 76% did not lose a single tooth due to periodontitis).
3. High adherence appears to weaken the association between an unstable PPS at baseline (i.e., a less than optimal result after active periodontal treatment) and an increased number of diseased teeth and tooth loss due to periodontitis.

CONFLICT OF INTEREST

The authors have no conflicts of interest related to the present study to declare.

AUTHOR CONTRIBUTIONS

Kristina Bertl: idea, analysis, interpretation, manuscript; Nikolaos Pandis: analysis; manuscript; Nikolaus Stopfer: data extraction,

manuscript; Hady Haririan, Corinna Bruckmann: interpretation, manuscript; Andreas Stavropoulos: idea, interpretation, manuscript.

DATA AVAILABILITY STATEMENT

Data available from the authors upon reasonable request.

ETHICS STATEMENT

The study protocol was approved by the local Ethics Committee (EK-Nr. 1010/2017) and followed the “Strengthening the Reporting of Observational studies in Epidemiology” checklist (Appendix S1).

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