J Clin Periodontol 2008; 35: 175–182 doi: 10.1111/j.1600-051X.2007.01182.x

Journal of Clinical Periodontology

Tooth loss after active periodontal therapy. 2: tooth-related factors

Bernadette Pretzl[1], Jens Kaltschmitt[1], Ti-Sun Kim[1], Peter Reitmeir[2] and Peter Eickholz[3]

[1]Section of Periodontology, Department of Conservative Dentistry, Clinic for Oral, Dental and Maxillofacial Diseases, University Hospital Heidelberg, Heidelberg, Germany; [2]Institute of Health Economics and Health Care Management, GSF-National Research Center for Environment and Health Neuherberg, Germany; [3]Department of Periodontology, Center of Dental, Oral, and Maxillofacial Medicine (Carolinum), Hospital of the Johann Wolfgang Goethe-University Frankfurt/Main, Frankfurt, Germany

Pretzl B, Kaltschmitt J, Kim T-S, Reitmeir P, Eickholz P. Tooth loss after active periodontal therapy. 2: tooth-related factors. J Clin Periodontol 2008; 35: 175–182. doi: 10.1111/j.1600-051X.2007.01182.x.

Abstract

Objective: To assess tooth-related factors contributing to tooth loss over a period of 10 years after completion of active periodontal therapy (APT).

Material and Methods: All patients who had received APT by the same experienced periodontist, 10 years before beginning the research, were recruited until 100 patients were re-examined. Examinations included, at the patient level: test for interleukin-1 polymorphism, compliance to supportive periodontal therapy (SPT), mean plaque scores during SPT; at the tooth level: assessment of baseline bone loss (type, amount), tooth type, furcation status and abutment status. Logistic multilevel regression was performed for statistical analysis.

Results: Hundred patients with 2301 teeth at the baseline (completion of APT) were retrospectively examined. One hundred fifty-five teeth were lost over 10 years after APT. Logistic multilevel regression identified high plaque scores, irregular attendance of SPT and age as patient-related factors significantly accounting for tooth loss. Tooth-related factors significantly contributing to tooth loss were baseline bone loss, furcation involvement and use as an abutment tooth. However, in patients with regular SPT, 93% of teeth with 60–80% bone loss at the baseline, survived 10 years.

Conclusion: The following tooth-related risk factors for tooth loss were identified: baseline bone loss, furcation involvement, and use as an abutment tooth.

Key words: abutment tooth; bone loss; furcation involvement; supportive periodontal therapy (SPT); tooth loss

Accepted for publication 8 November 2007

Attachment loss and tooth loss are quite rare occurrences in patients under supportive periodontal therapy (SPT). However, progression of periodontitis is not distributed evenly among patients, but accumulates in distinct risk patients (Hirschfeld & Wasserman 1978, McFall 1982, Goldman et al. 1986, Wood et al. 1989). Some factors characterizing periodontal at risk patients are already known: e.g. smoking (McGuire & Nunn 1996, Fardal et al. 2004, Chambrone & Chambrone 2006, Dannewitz et al. 2006, Leung et al. 2006, Eickholz et al. 2007), irregular SPT (Checchi et al. 2002, Eickholz et al. 2007), diabetes mellitus (Faggion et al. 2007). The influence of the polymorphism in the interleukin (IL)-1α (-889) and IL-1β ($+3953$) gene clusters is still controversial (Ehmke et al. 1999, McGuire & Nunn 1999, Laine et al. 2001, Eickholz et al. 2007, Huynh-Ba et al. 2007). Patient-related factors have to be considered for scheduling the SPT intervals. However, models trying to define tooth loss exclusively through patient-related parameters only partially explain the variation of this parameter. Tooth-related parameters are important in treatment planning of individual teeth (Persson 2005). A number of tooth-related factors have also been shown to influence tooth loss: periodontal bone loss (McGuire & Nunn 1996, Dannewitz et al. 2006, Faggion et al. 2007), tooth mobility (McGuire & Nunn 1996, Faggion et al. 2007), furcation involvement (McGuire & Nunn 1996, Dannewitz et al. 2006), depth of the infrabony component, tooth type (Muzzi et al. 2006), and tooth vitality (Faggion et al. 2007). Further parameters may be probable influencing factors: type of bone loss (vertical/horizontal), use as abutment tooth, root grooves. However, when analysing tooth-related factors patient-related factors have to be considered also.

The aim of this study was to assess tooth-related factors contributing to tooth loss in the 10 years following initiation of anti-infective therapy.

Conflict of interest and source of funding statement

The authors declare that they have no conflict of interests.

This study was self-funded by the authors and their institutions. Institut für angewandte Immunolgie (IAI), Zuchwill, Switzerland is acknowledged for providing analyses for IL-1 polymorphism.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

Material and Methods

Patients

All patients who fulfilled the following criteria:

- periodontal treatment (anti-infective therapy with subgingival debridement under local anaesthesia and periodontal surgery if required) at the Section of Periodontology at the Department of Conservative Dentistry, Clinic for Oral, Dental, and Maxillofacial Diseases at the University Hospital Heidelberg beginning in October 1992 by the same trained periodontal specialist (P. E.).
- X-ray status obtained before periodontal treatment

were consecutively recruited 10 years $\pm$ 6 months after initiation of therapy (first appointment of periodontal treatment) for this study until 100 qualifying patients had been included. The study was approved by the Institutional Review Board for Human Studies of the Medical Faculty of Heidelberg University (Application# 331/2002). All participating patients were informed about possible risks and benefits as well as the procedures of the study and all gave written informed consent.

Clinical examinations

The re-examinations performed by an independent examiner (B. P.) have been reported in detail in a companion paper (Eickholz et al. 2007). Thus, only a brief description of the clinical examinations is provided: gingival bleeding index (GBI; Ainamo & Bay 1975) and plaque control record (PCR; O'Leary et al. 1972) were scored and probing pocket depths (PPD) and vertical attachment levels (PAL-V) were assessed to the nearest 1 mm using a manual periodontal probe (PCPUNC 15; Hu Friedy, Chicago, IL, USA) in six sites per tooth. Bleeding (BOP) and suppuration (SUP) were recorded 30 s after probing. In multirooted teeth furcation involvement (Hamp et al. 1975) was assessed using a Nabers probe marked in 3 mm steps (PQ2N; Hu Friedy). All patients were tested for IL-1 polymorphism (IL-1A -889, IL-1B $+3953$). Retrospectively, each patient was assigned a baseline diagnosis (e.g. generalized moderate chronic periodontitis) according to the actual classification of periodontal diseases (Armitage 1999).

Evaluation of radiographs

Before active periodontal treatment (subgingival debridement and periodontal surgery if required) complete sets of periapical radiographs of each patient (Ultraspeed; Kodac, Rochester, NY, USA) were obtained in XCP format using film holders (XCP, Kentzler & Kaschner Dental, Ellwangen/Jagst, Germany). Dental films of intraoral size 0 (maxillary canines and mandibular anteriors) and two (all other regions) were exposed to an X-ray source (Heliodent 70®, 70 kV, 7 mA, Sirona, Bensheim, Germany) and developed under standardized conditions (Periomat®, Dürr Dental, Bietigheim-Bissingen, Germany).

All radiographs were viewed in a darkened room using a radiograph screen (67–0420, Dentsply Rinn, Elgin, IL, USA). Relative percentage bone loss was assessed at the most periodontally affected site of each tooth using a Schei ruler (Schei et al. 1959). Teeth were assigned (i) to one of five groups of periodontal bone loss ($<20\%$, 20% to $<40\%$, 40% to $<60\%$, 60% to $<80\%$, 80% and more) (Kim et al. 2007) and (ii) according to periodontal bone loss ($<50\%$, 50–75%, $>75\%$) in conjunction with furcation involvement to one of three groups for the assessment of tooth-related prognosis (hopeless, questionable, good) (Checchi et al. 2002).

Furthermore, at the interproximal site with the most severe bone loss of each tooth, the type of bone loss was characterized as horizontal or vertical (infrabony defect). At each infrabony defect the depth of the infrabony component was measured to the next 0.1 mm using a loupe with 10-fold magnification (scale loupe $\times 10$, Peak, Tohkai Sangyo, Tokyo, Japan) (Eickholz et al. 1996). Each infrabony defect was allocated to one of three groups: shallow (2 mm), moderate (2.5–4 mm), and deep ($\geqslant 4.5$ mm) defects (Papapanou & Wennström 1991). For each tooth it was assessed whether a double contour of the root could be detected. A double contour was interpreted as indicator for a mesial or distal root groove.

According to the clinical and radiographic findings each tooth was assigned to one of three prognostic groups (Checchi et al. 2002).

- *hopeless*: bone loss $>75\%$ or teeth that had at least two characteristics of the ''questionable'' category;
- *questionable*: bone loss between 50% and 75% or the presence of an angular defect (infrabony component >2 mm) or furcation involvement;
- *good*: bone loss $<50\%$ or not fitting one of the two previous categories.

Radiographic assessments were performed by an independent examiner blinded for clinical measurements and therapy rendered (J. K.).

Evaluation of patients' charts

For each patient, it was documented whether he or she had attended SPT at the Section of Periodontology at the University Hospital Heidelberg regularly complying with the intervals that had been recommended. If a patient had extended the recommended SPT interval at least once by more than 100% he or she was assigned to the irregular SPT group (e.g. the recommended SPT interval was 6 months and the patient returned for SPT after 13 months) (Eickholz et al. 2007).

The following tooth-related parameters were assessed from the patients' charts as well:

- *Jaw*: maxilla or mandible.
- *Tooth type*: anterior, premolar, molar.
- *Furcation involvement*: Teeth were distinguished by single-rooted teeth (0) and multi-rooted teeth without (1) or with (2) baseline furcation involvement, respectively. Not all patients' charts provided baseline information on different degrees of furcation involvement (Hamp et al. 1975). Thus, analysis considering different degrees of furcation involvement could not be performed.
- *Abutment tooth*: Each tooth was classified according to a baseline status as: no abutment tooth (0), abutment tooth for fixed (1), or removable (2) prosthodontic constructions.

SPT

SPT encompassed the following elements for all patients at each appointment: Assessment of GBI and PCR as amount of positive (bleeding for GBI, plaque for PCR) in percentages of all assessed sites, re-instruction and re-motivation to effective individual

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

plaque control, professional tooth cleaning with hand instruments and polishing of all teeth using rubber cups and polishing paste, application of a fluoride gel. Twice a year a dental status and PPD were obtained for four sites per tooth. Thirty seconds after probing BOP was recorded. Sites exhibiting PPD = 4 mm and BOP as well as sites with PPD ⩾ 5 mm were scaled subgingivally. If a patient exhibited more than five to six sites that ought to be debrided subgingivally, repeated anti-infective therapy was recommended. From 1992 to 1999 assignment of SPT intervals was not performed according to strict criteria. SPT was provided to most patients at 3-month intervals during the first year of SPT and later on 6-month intervals. Patients exhibiting ineffective plaque control (PCR > 35%) or with aggressive periodontitis (at that time juvenile and rapidly progressive periodontitis) were seen four times a year for SPT (3-month intervals). However, the intervals were not fixed. A patient after treatment of aggressive periodontitis with effective plaque control and without residual pockets was seen only two times a year. From October 1999 the assignment of SPT intervals was performed according to the periodontal risk assessment (PRA) (Ramseier & Lang 1999, Lang & Tonetti 2003, Eickholz et al. 2007).

Statistical analysis

The patient was looked upon as the statistical unit and tooth loss after APT was defined as the main outcome variable. Statistical analysis was performed using different computer programs: Data entry and descriptive statistics (Systat™ for Windows Version 10, Systat Inc. Evanston, USA). Logistic multilevel analysis was modelled by an independent statistician (P. R.) using another program (SAS® version 6.12, SAS Institute, Cary, NC, USA).

A logistic multilevel regression was modeled to explain the variation of the binomial dependent variable tooth loss. For all analyses the basic level ''tooth'' was nested into the upper level ''patient''. All patient effects were assumed to be random (Goldstein 1995). The following independent patient-related variables were entered into the model sex, age, IL-1 polymorphism, diagnosis, smoking, regular SPT participation (yes/no); tooth-related variables: relative amount of interproximal bone loss, type of bone loss (horizontal/vertical), in case of vertical bone loss depth of infrabony component, tooth type (anterior, pre-molar, molar), jaw (maxilla/mandible), furcation involvement (single-rooted tooth, multi-rooted tooth without or with furcation involvement), abutment tooth (no/fixed or removable prosthesis). The amount of interproximal bone loss relative to root length was recorded in five different categories (1, < 20%; 2, ⩾ 20% to < 40%; 3, ⩾ 40% to < 60%; 4, ⩾ 60% to < 80%; 5, ⩾ 80%). Third molars were excluded from the analysis.

Results

Patients

A total of 145 patients were invited to participate in the study according to the schedule of therapy initiation 10 years ± 6 months before beginning of the research. Forty-two of these patients were not able or not willing to be re-examined. Therefore the respondent rate was 71%. Three further patients had to be excluded during analysis due to incomplete data (Eickholz et al. 2007). Thus, a total of 100 patients contributing 2301 teeth at the end of active periodontal treatment were included into the analysis. Table 1 gives mean age and gender distribution of the sample. Further demographic data are given in the companion paper on patient-related factors (Eickholz et al. 2007). A total of 155 teeth were lost after APT: 29 in the regular SPT group and 126 in the irregular SPT group. Most teeth in the total sample had a baseline interproximal bone loss between 20% and < 40%. Most severe bone loss (⩾ 80%) was observed only in a total of 52 teeth. More than half of all teeth were single rooted. Three hundred and ninety of the 699 multi-rooted teeth exhibited furcation involvement of any kind. The majority of teeth were not used as an abutment tooth for any kind of prostheses. Two hundred thirty-two teeth were abutment teeth for fixed and 67 for removable reconstructions. About 80% of all teeth had a good baseline prognosis, 385 a questionable, and 122 a hopeless prognosis (Checchi et al. 2002) (Table 1). Forty-four of all patients were assigned to SPT at 3-month intervals

Table 1. Patient and tooth characteristics: distribution of teeth according to bone loss, tooth type, furcation involvement, use as abutment tooth, and prognosis

	Total	Non-compliant with SPT	Compliant with SPT
Patients	N = 100	N = 47	N = 53
Sex (female)	59	30	29
Age (years)	46.5 ± 10.3	45.3 ± 10.2	47.6 ± 10.3
Initial diagnosis			
Moderate ChP	30	14	16
Severe ChP/AgP	60/10	28/5	32/5
Teeth	N = 2301	N = 1056	N = 1245
Periodontal bone loss			
< 20%	661	284	377
20%/ < 40%	964	446	518
40%/ < 60%	482	224	258
60%/ < 80%	142	68	74
⩾ 80%	52	34	18
Tooth type			
Anterior	1094	500	594
Pre-molar	657	307	350
Molar	550	249	301
Furcation involvement (FI)			
Single-rooted teeth	1602	740	862
Multi-rooted teeth			
Without FI	309	137	172
With FI	390	179	211
Abutment tooth			
No abutment tooth	2002	904	1098
Fixed	232	113	119
Removable	67	39	28
Prognosis			
Good	1794	810	984
Questionable	385	175	210
Hopeless	122	71	51

SPT, supportive periodontal therapy.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

Table 2. Logistic multilevel regression analysis: tooth loss during supportive periodontal therapy (SPT) related to retrospective factors

	Estimate	p	t-value	Odds ratio
Intercept	− 14.0305	< 0.0001	− 8.35	
Irregular SPT	1.5204	0.0002	3.77	4.57
Smoking	0.8678	0.0628	1.86	2.38
Mean PCR	0.5835	0.0006	3.43	1.79
Age	0.0851	0.0001	3.88	1.09
Diagnosis (severe ChP/AgP)	0.6865	0.1307	1.51	1.99
Sex (female)	0.5467	0.1571	1.42	1.72
Interleukin-1 polymorphism	0.5376	0.1527	1.43	1.71
Bone loss	0.8748	< 0.0001	7.47	2.40
Furcation involvement	0.7479	< 0.0001	5.98	2.11
Abutment tooth	0.5525	0.0050	2.81	1.74

Dependent variable: tooth loss; $n = 100$ patients/2301 teeth.
PCR, plaque control record; SPT, supportive periodontal therapy.

Table 3. Tooth loss over 10 years after active periodontal treatment in relation to baseline periodontal bone loss: (a) total, (b) regular, and (c) irregular supportive periodontal therapy (SPT)

	Baseline bone loss in % of root length					
	Total	< 20%	⩾20% to < 40%	⩾40% to < 60%	⩾60% to < 80%	⩾80%
(a) Total						
N	2301	661	964	482	142	52
Loss *n*	155	21	43	45	28	18
Loss %	7	3	4	9	20	35
(b) Regular SPT						
N	1245	377	518	258	74	18
Loss *n*	29	5	9	6	5	4
Loss %	2	1	2	2	7	22
(c) Irregular SPT						
N	1056	284	446	224	68	34
Loss *n*	126	16	34	39	23	14
Loss %	12	6	8	17	34	41

Table 5. Tooth loss over 10 years after active periodontal treatment in relation to baseline status as abutment tooth: (a) total, (b) regular, and (c) irregular supportive periodontal therapy (SPT)

	Total	No abutment tooth	Abutment tooth	
			fixed	removable
			prosthesis	
(a) Total				
N	2301	2002	232	67
Loss *n*	155	115	28	12
Loss %	7	6	12	18
(b) Regular SPT				
N	1245	1098	119	28
Loss *n*	29	18	10	1
Loss %	2	2	8	4
(c) Irregular SPT				
N	1056	904	113	39
Loss *n*	126	97	18	11
Loss %	12	11	16	28

Table 6. Tooth loss over 10 years after active periodontal treatment in relation to baseline single tooth prognosis (Checchi et al. 2002): (a) total, (b) with, and (c) without regular supportive periodontal therapy (SPT)

	Total	Good	Questionable	Hopeless
(a) Total				
N	2301	1794	385	122
Loss *n*	155	77	43	35
Loss %	7	4	11	29
(b) Regular SPT				
N	1245	984	210	51
Loss *n*	29	16	6	7
Loss %	2	2	3	14
(c) Irregular SPT				
N	1056	810	175	71
Loss *n*	126	61	37	28
Loss %	12	8	21	39

during the first year after APT and later on 6-month intervals. Twenty-one patients were assigned to 3 months and 35 patients were scheduled for 6-month intervals for the majority appointments.

Tooth loss

Logistic multilevel regression analysis identified the following factors to influence tooth loss: at patient level: irregular participation in SPT ($p = 0.0002$), mean PCR during SPT ($p = 0.0006$), age ($p = 0.0001$); at tooth level: baseline interproximal bone loss ($p < 0.0001$), furcation involvement ($p < 0.0001$), and abutment tooth ($p = 0.005$) (Table 2). Regular participation in SPT prevented tooth loss with an odds ratio of 4.57. Individual plaque control assessed as mean PCR during SPT correlated with tooth loss. The risk for tooth loss increased with an odds ratio of 1.79

Table 4. Tooth loss over 10 years after active periodontal treatment in relation to baseline furcation involvement: (a) total, (b) regular, and (c) irregular supportive periodontal therapy (SPT)

	Total	Single-rooted teeth	Multi-rooted teeth	
			without	with
			furcation involvement	
(a) Total				
N	2301	1602	309	390
Loss *n*	155	74	30	51
Loss %	7	5	10	13
(b) Regular SPT				
N	1245	862	172	211
Loss *n*	29	7	6	16
Loss %	2	1	3	8
(c) Irregular SPT				
N	1056	740	137	179
Loss *n*	126	67	24	35
Loss %	12	9	18	20

for each additional 10% increase in the plaque score. The amount of baseline bone loss, furcation involvement, and use as an abutment tooth were associated with a higher risk for tooth loss. The total and relative tooth loss for the entire sample as well as for the regular and irregular SPT group separately are given in Table 3 (bone loss), Table 4 (furcation involvement), Table 5 (abutment tooth), and Table 6 (prognosis). Additional putative tooth-related risk factors for tooth loss as type of bone loss (horizontal or vertical) or presence of mesial or distal root grooves (radiographic double contour of the root) failed to reach statistical significance in the logistic multilevel regression model.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

Although patient charts were searched and all participants of this study were asked, the causes of extractions could only partly be revealed in particular for teeth that had been removed alio loco.

Discussion

Patients

All patients for whom the senior author (P. E.) had initiated periodontal treatment systematically 10 years ± 6 months before this research, were consecutively invited for a re-examination. Not only those patients were invited who still were under regular treatment at the Section of Periodontology, but also patients who had quit treatment there due to various reasons (e.g. moving away, continuation of therapy at other dentists). Earlier retrospective studies re-examined only patients that still were under frequent therapy at the study site or they gave no information on the respondent rate (Hirschfeld & Wasserman 1978, McFall 1982, Goldman et al. 1986, Wood et al. 1989, Checchi et al. 2002, Fardal et al. 2004, Chambrone & Chambrone 2006, Muzzi et al. 2006). Most retrospective analyses report that patients had attended SPT throughout the whole period before re-examination (Hirschfeld & Wasserman 1978, McFall 1982, Goldman et al. 1986, Wood et al. 1989, Fardal et al. 2004, Chambrone & Chambrone 2006, Muzzi et al. 2006, Faggion et al. 2007, Carnevale et al. 2007a, b).

Tooth loss

Patient-related risk factors for tooth loss were analysed in a companion paper and identified plaque scores during SPT, irregular attendance of SPT, IL-1 polymorphism, age, initial diagnosis, smoking, and sex (Eickholz et al. 2007). Thus, these seven patient-related factors were also entered into this tooth-related analysis. After entering tooth-related factors into a logistic multilevel regression model IL-1 polymorphism, initial diagnosis, smoking, and sex failed to turn out as significant risk factors for tooth loss. If IL-1 polymorphism, initial diagnosis, smoking, and sex increase the risk for periodontitis (McGuire & Nunn 1999, Eickholz et al. 2007), patients carrying these factors are likely to exhibit more bone loss and furcation involvement. Consideration of bone loss and furcation involvement on a tooth level may have obscured the effect of the patient-related factors. Applying multilevel modelling and entering bone loss and tooth type into analysis, IL-1 polymorphism was not kept in the model by other authors either (Muzzi et al. 2006).

It is plausible that already existing severe bone loss before therapy is associated with a high risk for tooth loss caused by further attachment loss. This relation has been shown by other authors before (Papapanou et al. 1989, McGuire & Nunn 1996, Dannewitz et al. 2006, Muzzi et al. 2006, Faggion et al. 2007). However, even in patients with already existing severe bone loss SPT plays a significant role: in patients attending SPT regularly 78% of teeth exhibiting baseline relative bone loss ⩾80% survived 10 years. In patients with irregular SPT only 59% of those teeth survived 10 years. In the regular SPT group 93% of teeth with baseline bone loss from 60% to 80% of root length survived 10 years. This number easily matches with success rates of intraosseous implants in periodontally compromised patients (Karoussis et al. 2007).

The effect of furcation involvement on survival rates of teeth has been reported before (Hirschfeld & Wasserman 1978, McGuire & Nunn 1996). In this study furcation involvement was not subdivided into different degrees (e.g. Hamp et al. 1975). In the years 1992–1994 differentiated furcation involvements were not recorded consistently. For some teeth it was just documented that the furcation could be probed with a Nabers probe, others had already been assigned to one of 4 degrees (Hamp et al. 1975). For this analysis we could only distinguish between furcation involvement or not. Our results confirm the observation that furcation involved teeth have a worse prognosis (13% tooth loss) than single rooted teeth (5%) or multirooted teeth without furcation involvement (10%). Another analysis on survival of molar teeth including only molars with baseline assignment to different degrees of furcation involvement failed to identify furcation involvement in general as a risk factor for tooth loss, but reported furcation degree III (through-and-through) to be associated with significantly increased rates of tooth loss (Dannewitz et al. 2006). Other authors reported similar survival rates (approximately 90%) for class I furcated molars and molars without furcation involvement. However, after 12 years of SPT 25% of molars with class II furcation involvement were lost and 39% of through-and-through furcation molars (McGuire & Nunn 1996).

The variable tooth type (anterior, premolar, molar) which had been entered into the logistic multilevel regression, failed to statistically significantly influence tooth loss. At first this contradicts observations of another working group that had reported increased risk of tooth loss in molars compared with other tooth types (Muzzi et al. 2006). However, they did not consider furcation involvement. Faggion et al. (2007) reported worse prognosis for multirooted than for single-rooted teeth. Although they also did not consider furcation involvement (Faggion et al. 2007). The present analysis confirmed the worse prognosis of multi-rooted teeth even without furcation involvement compared with single-rooted teeth. However, furcation involvement further increased the risk for tooth loss of multirooted teeth (Table 4). Thus, it may be concluded that not molars but multirooted teeth (first maxillary premolars as well) have an increased risk for loss and that furcation involvement is another important aspect (McGuire & Nunn 1996, Dannewitz et al. 2006).

Interestingly, teeth that had been included into fixed or removable dentures before periodontal therapy exhibited higher rates of tooth loss than teeth that were not used as abutments. Removable reconstructions had an even worse effect than fixed bridgework. The rate of tooth loss over 10 years in fixed bridgework is doubled in relation to teeth that are not used as abutments (no abutment: 6%; abutment in fixed construction: 12%) and further increased in removable dentures (18%). Lulic et al. (2007) estimated a 5% loss of abutment teeth of cross-arch fixed bridgework 10 years after insertion in a severely periodontally compromised but frequently maintained (⩾1 SPT per year) sample reported by Yi et al. (1995) and Lulic et al. (2007). This study reports 8% loss of abutment teeth of fixed bridgework after 10 years in the regular SPT group. The rate of SPT in the regular SPT group of this study and in the Yi et al. (1995) study is rather comparable. Teeth used as abutments are often harder to clean for the patient and thus carry the risk for reinfection and progression of disease. Finally preparation of a tooth to be used as an abutment increases the

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

risk of endodontic complications (Goodacre et al. 2003, Lulic et al. 2007) that may also lead to tooth loss.

It is well known that particularly removable dentures deteriorate the periodontal conditions of abutment teeth (Knezović Zlatarić et al. 2002). The rate of tooth loss for abutment teeth observed in this study confirms survival rates for abutment teeth of telescopic dentures (Mock et al. 2005). These observations should be particularly considered before the extraction of putative hopeless teeth (Checchi et al. 2002) because such extractions may create the need for prosthetic treatment. Some of these ''hopeless'' teeth may have had a better prognosis than those teeth that are required and used as abutments after extraction. This observation confirms and underlines the significance of the concept of shortened arches as a tool to avoid prosthetic treatment (Witter et al. 1999).

Muzzi et al. (2006) had also considered restorations as parameter to explain tooth loss. However, the parameter was not kept in the regression model as significant factor. How can this difference be explained? Muzzi et al. have taken into account all restored teeth, i.e. single crowns as well as abutments for fixed and removable dentures. In this analysis, we used the parameter abutment and not just restoration to distinguish risk for tooth loss.

Other analyses have included the parameters of tooth vitality and mobility, however, did not account for restoration or abutment. Tooth vitality and mobility were observed as significant predictors for tooth loss: non-vital and severely mobile teeth (degree 3) exhibited a higher rate of tooth loss than vital or firm teeth (degree 0) (Faggion et al. 2007). Other authors have included tooth mobility as a tooth-related factor into their analysis (degree 0–3) and failed to observe a significant effect (Muzzi et al. 2006). These discrepant observations may be explained by the fact that dichotomisation to the extreme values degrees 0 and 3 (Faggion et al. 2007) creates a stronger effect of the factor tooth mobility than inclusion of all 4 degrees (0–3) (Muzzi et al. 2006). Another explanation could be the use of different classifications. The present analysis did not consider mobility because the classification of mobility used at the time of baseline examination did not allow precise and reliable distinctions (degree 0: physiological mobility; I: palpable mobility; II: visible mobility; III: teeth mobile due to pressure of tongue or lip or axial mobility). Use of tooth vitality to explain tooth loss is a problem if the differences between properly root canal filled teeth, pulp necrosis or periapical lesions are not taken into account. The different diagnoses that may cause a negative response to vitality testing have quite a different prognostic significance. Instead of dichotomising (vital/non-vital), more than two categories may have been more appropriate (e.g. vital/root canal treated/pulp necrosis and periapical lesion) to explain tooth loss.

Furthermore, tooth-related risk factors as the type of bone loss (horizontal or vertical) or presence of mesial or distal root grooves (radiographic double silhouette) were not kept in the logistic regression model as statistically significant factors. Of particular interest is the observation that not the type of bone loss (horizontal or vertical), but bone loss relative to total root length is the significant factor for tooth loss. This contradicts observations made by other authors: in 201 patients, full sets of periapical radiographs were obtained in a time interval of 10 years. For horizontal bone loss a rate of tooth loss of 13% was reported. In infrabony defects (vertical bone loss) depending on the depths of the infrabony component a tooth loss rate of 22%, 46%, and 68%, respectively, was found (Papapanou & Wennström 1991). That study analysed a sample double the size of the sample of this study and has a better test power. Papapanou & Wennström (1991) generally report significantly more tooth loss (13–68%). This may be plausibly explained by the fact that the Papapanou & Wennström sample was not treated periodontally. Patients in the present study had all been treated systematically anti-infectively and surgically if it was required. Fifty-three of these patients attended SPT regularly over the complete observation period. It may be speculated that baseline vertical defects in periodontally treated patients do not have significant influence on future tooth loss. On the contrary in another sample, the baseline depth of infrabony defects correlated inversely to tooth loss, i.e. the deeper the infrabony component at baseline the smaller the risk for tooth loss (Muzzi et al. 2006). The authors try to explain this observation with the fact that deep infrabony pockets respond very well to regenerative therapy. It may be speculated that many infrabony defects had been treated using regenerative techniques in that sample and that this therapy resulted in bony fill of the defects. To clearly judge this effect, regenerative periodontal treatment as a tooth-related factor should have been included in the multilevel regression model.

Although patient charts were searched and all participants of this study were asked, the causes of extractions could not be revealed in particular for teeth that had been removed alio loco. This is a potential problem of studies including patients who have quit regular SPT. The information on the influence of regular/irregular SPT is gained. However, it becomes more difficult and sometimes impossible to collect information on reasons of extraction. Carnevale et al. (2007b) who reported on a frequent SPT sample saw root fractures as the most frequent reason for extraction followed by periodontal reasons (Carnevale et al. 2007b).

Prognosis

Already Hirschfeld & Wasserman (1978) had attempted to assign a prognosis to teeth in advance. They distinguished between favorable and questionable prognosis. A questionable prognosis was assigned to a tooth if it showed one or more of the following criteria: (i) furcation involvement, (ii) deep non-eradicable pocket, (iii) extensive alveolar bone loss, (iv) marked mobility in conjunction with pocket depth (2 or 2.5 on a scale of 3) (Hirschfeld & Wasserman 1978, McFall 1982). These criteria are not defined accurately and leave a large latitude of judgement. The rate of tooth loss of such questionable teeth without furcation involvement was 30%. However, the rate of tooth loss varied from 12% in the well-maintained subgroup, over 55% in the downhill, to 92% in the extreme downhill subgroup (Hirschfeld & Wasserman 1978). Hirschfeld & Wasserman considered only tooth related factors for their prognosis. Patient-related factors such as sex, age or smoking were not incorporated. However, evidently patient-related or other tooth-related factors played an important role for tooth loss (Hirschfeld & Wasserman 1978).

Interestingly single tooth prognosis according to Checchi et al. (2002) was not reliable in the investigated sample.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

Bone loss in percent relative to root length is a strong predictor for loss of single teeth. Single tooth prognosis according to Checchi et al. (2002) considers relative bone loss. However, the Checchi prognosis system does not take into account further factors that have been identified in this study (Checchi et al. 2002). The patient-related factor of regular participation in SPT is of paramount significance: only 14% of the teeth that were judged as ''hopeless'' due to baseline parameters were actually lost in the regular SPT group, i.e. 86% of ''hopeless'' teeth survived 10 years. In the irregular SPT group actually 39% of ''hopeless'' teeth were lost. Even that rate of tooth loss over a period of 10 years does not fit into the real meaning of the word ''hopeless''. Furcation involvement and use as an abutment also increase the risk for tooth loss. Use as an abutment deteriorates the prognosis of a single tooth in addition to bone loss. In this context, abutment teeth for removable prostheses have a worse prognosis than abutments for fixed constructions.

Conclusions

- In patients after active periodontal treatment, regular SPT and effective plaque control are strong patient-related factors to prevent tooth loss.
- The following tooth-related risk factors increase the risk for tooth loss: baseline bone loss, furcation involvement, and use as an abutment tooth.

Acknowledgements

We wish to thank Almut von Schwedler, MD, Matcham, NSW, Australia and Leigh Stevens, London, Great Britain, for their valuable and competent support in the preparation of this manuscript.

References

Ainamo, J. & Bay, I. (1975) Problems and proposals for recording gingivitis and plaque. *International Dental Journal* **25**, 229–235.

Armitage, G. C. (1999) Development of a classification system for periodontal diseases and conditions. *Annals of Periodontology* **4**, 1–6.

Carnevale, G., Cairo, F. & Tonetti, M. S. (2007a) Long-term effects of supportive therapy in periodontal patients treated with fibre retention osseous resective surgery. I: recurrence of pockets, bleeding on probing and tooth loss. *Journal of Clinical Periodontolgy* **34**, 334–341, doi: 10.1111/j.1600-051X.2007.01051.x.

Carnevale, G., Cairo, F. & Tonetti, M. S. (2007b) Long-term effects of supportive therapy in periodontal patients treated with fibre retention osseous resective surgery. II: tooth extractions during active and supportive therapy. *Journal of Clinical Periodontolgy* **34**, 342–348, doi: 10.1111/j.1600-051X.2007.01052.x.

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, doi: 10.1111/j.1600-051X.2006.00972.x.

Checchi, L., Montevecchi, M., Gatto, M. R. A. & Trombelli, L. (2002) Retrospective study of tooth loss in 92 treated periodontal patients. *Journal of Clinical Periodontolgy* **29**, 651–656.

Dannewitz, B., Krieger, J. K., Hüsing, J. & Eickholz, P. (2006) Loss of molars in periodontally treated patients: a retrospective analysis five years or more after active periodontal treatment. *Journal of Clinical Periodontolgy* **33**, 53–61, doi: 10.1111/j.1600-051X.2005.00858.x.

Ehmke, B., Kreß, W., Karch, H., Grimm, T., Klaiber, B. & Flemmig, T. F. (1999) Interleukin-1 haplotype and periodontal disease progression following therapy. *Journal of Clinical Periodontology* **26**, 810–813.

Eickholz, P., Benn, D. K. & Staehle, H. J. (1996) Radiographic evaluation of bone regeneration following periodontal surgery with or without expanded polytetrafluoroethylene barriers. *Journal of Periodontology* **67**, 379–385.

Eickholz, P., Kaltschmitt, J., Berbig, J., Reitmeir, P. & Pretzl, B. (2007) Tooth loss after active periodontal therapy. 1. Patient-related factors for risk, prognosis, and quality of outcome. *Journal of Clinical Periodontology* **35**, 166–175.

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, doi: 10.1111/j.1600-051X.2006.01045.x.

Fardal, Ø., Johannessen, A. C. & Linden, G. J. (2004) Tooth loss during maintenance following periodontal treatment in a periodontal practice in Norway. *Journal of Clinical Periodontology* **31**, 550–555, doi: 10.1111/j.1600-051X.2004.00519.x.

Goldman, M. J., Ross, I. F. & Goteiner, D. (1986) Effect of periodontal therapy on patients maintained for 15 years or longer. A retrospective study. *Journal of Periodontology* **57**, 347–353.

Goldstein, H. (1995) *Multilevel statistics models*. London: Edward Arnold.

Goodacre, C. J., Bernal, G., Rungcharassaeng, K. & Kan, J. Y. (2003) Clinical complications in fixed prosthodontics. *Journal of Prosthetic Dentistry* **90**, 31–41.

Hamp, S.-E., 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.

Huynh-Ba, G., Lang, N. P., Tonetti, M. S. & Salvi, G. E. (2007) The association of the composite IL-1 genotype with periodontitis progression and/or treatment outcomes: a systematic review. *Journal of Clinical Periodontolgy* **34**, 305–317, doi: 10.1111/j.1600-051X.2007.01055.x.

Karoussis, I. K., Kotsovlis, S. & Fourmousis, I. (2007) A comprehensive and critical review of dental implant prognosis in periodontally compromised partially edentulous patients. *Clinical Oral Implants Research* **18**, 669–679.

Kim, T.-S., Schenk, A., Lungeanu, D., Reitmeir, P. & Eickholz, P. (2007) Non-surgical and surgical periodontal therapy in single rooted teeth. *Clinical Oral Investigations* **11**, 391–399.

Knezović Zlatarić, D., Asjâ Čelebić, A. & Melita Valentić-Peruzović, M. (2002) The effect of removable partial dentures on periodontal health of abutment and non-abutment teeth. *Journal of Periodontology* **73**, 137–144.

Laine, M. L., Farré, M. A., García-González, M. A., van Dijk, L. J., Ham, A. J., Winkel, E. G., Crusius, J. B. A., Vandenbrouke, J. P., van Winkelhoff, A. J. & Peña, A. S. (2001) Polymorphisms of the interleukin-1 gene family, oral microbial pathogens, and smoking in adult periodontitis. *Journal of Dental Research* **80**, 1695–1699.

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

Leung, W. K., Ng, D. K. C., Jin, L. & Corbet, F. (2006) Tooth loss in treated periodontitis patients responsible for their supportive care arrangements. *Journal of Clinical Periodontology* **33**, 265–275, doi: 10.1111/j.1600-051X.2006.00903.x.

Lulic, M., Brägger, U., Lang, N. P., Zwahlen, M. & Salvi, G. E. (2007) Ante's (1926) law revisited: a systematic review on survival rates and complications of fixed dental prostheses (FDPs) on severely reduced periodontal tissue support. *Clinical Oral Implants Research* **18** (Suppl. 3), 63–72, doi: 10.1111/j.1600-0501.2007.01438.x.

McFall, W. T. (1982) Tooth loss in 100 treated patients with periodontal disease. A long term study. *Journal of Periodontology* **53**, 539–549.

McGuire, M. K. & Nunn, M. E. (1996) Prognosis versus actual outcome. III. The effectiveness of clinical Parameters in developing an accurate prognosis. *Journal of Periodontology* **67**, 666–674.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard

McGuire, M. K. & Nunn, M. E. (1999) Prognosis versus actual outcome. IV. The effectiveness of clinical parameters and IL-1 genotype in accurately predicting prognoses and tooth survival. *Journal of Periodontology* **70**, 49–56.
Mock, F., Schrenker, H. & Stark, H. K. (2005) Eine klinische Langzeitstudie von Teleskopprothesen. *Deutsche Zahnärztliche Zeitschrift* **60**, 148–153.
Muzzi, L., Nieri, M., Cattabriga, M., Rotundo, R., Cairo, F. & Pini Prato, G. P. (2006) The potential prognostic value of some periodontal factors for tooth loss: a retrospective multilevel analysis on periodontal patients treated and maintained over 10 years. *Journal of Periodontology* **77**, 2084–2089.
O'Leary, T. J., Drake, R. B. & Naylor, J. E. (1972) The plaque control record. *Journal of Periodontology* **43**, 38.
Papapanou, P. N. & Wennström, J. L. (1991) The angular bony defect as indicator of further alveolar bone loss. *Journal of Clinical Periodontology* **18**, 317–322.
Papapanou, P. N., Wennström, J. L. & Gröndahl, K. (1989) A 10-year retrospective study of periodontal disease. *Journal of Clinical Periodontology* **16**, 403–411.
Persson, G. R. (2005) Site-based versus subject-based periodontal diagnosis. *Periodontology 2000* **39**, 145–163.
Ramseier, C. A. & Lang, N. P. (1999) *Die Parodontalbetreuung. Ein Lernprogramm zur Qualitätssicherung in der Parodontologie (CD-Rom)*. Berlin: Quintessenz Verlag.
Schei, O., Waerhaug, J., Lovdal, A. & Arno, A. (1959) Alveolar bone loss as related to oral hygiene and age. *Journal of Periodontology* **30**, 7–16.
Witter, D. J., van Palenstein Helderman, W. H., Creugers, N. H. & Kayser, A. F. (1999) The shortened dental arch concept and its implications for oral health care. *Community Dentistry and Oral Epidemiology* **27**, 249–258.
Wood, W. R., Greco, G. W. & McFall, W. T. Jr. (1989) Tooth loss in patients with moderate periodontitis after treatment and long-term maintenance care. *Journal of Periodontology* **60**, 516–520.
Yi, S.-W., Ericsson, I., Carlsson, G. E. & Wennström, J. L. (1995) Long-term follow-up of cross-arch fixed partial dentures in patients with advanced periodontal destruction. Evaluation of the supporting tissues. *Acta Odontologica Scandinavica* **53**, 242–248.

Address:
Peter Eickholz
Poliklinik für Parodontologie
Zentrum der Zahn-, Mund- und Kieferheilkunde (Carolinum)
Klinikum der Johann Wolfgang Goethe-Universität Frankfurt am Main
Theodor-Stern-Kai 7, 60590 Frankfurt am Main
Germany
E-mail: eickholz@med.uni-frankfurt.de

Clinical Relevance

Scientific rationale for the study: Long-term retention of teeth in function is the ultimate goal of periodontal therapy. Tooth loss may be determined by patient- and tooth-related factors. This study aimed to identify tooth-related factors.

Principal findings: Baseline bone loss, furcation involvement, and use as an abutment tooth contribute to the risk of tooth loss.

Practical implications: Even accounting for tooth-related factors regular supportive periodontal therapy and effective plaque control are the most valid tools to prevent tooth loss.

© 2008 The Authors. Journal compilation © 2008 Blackwell Munksgaard