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ORIGINAL ARTICLE

Long-term prognosis of teeth with class III furcation involvement

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Abstract

Objective: Evaluation of survival of teeth with class III furcation involvement (FI) ≥5 years after active periodontal treatment (APT) and identification of prognostic factors.

Methods: All charts of patients who completed APT at the Department of Periodontology of Goethe-University Frankfurt, Germany, beginning October 2004 were screened for teeth with class III FI. APT had to be accomplished for ≥5 years. Charts were analysed for data of class III FI teeth at baseline (T0), at accomplishment of APT (T1), and at the last supportive periodontal care (T2). Baseline radiographic bone loss (RBL) and treatment were assessed.

Results: One-hundred and sixty patients (age: 54.4 ± 9.8 years; 82 females; 39 active smokers; 9 diabetics, 85 stage III, 75 stage IV, 59 grade B, 101 grade C) presented 265 teeth with class III FI. Ninety-eight teeth (37%) were lost during 110, 78/137 (median, lower/upper quartile) months. Logistic mixed-model regression and mixed Cox proportional hazard model associated adjunctive systemic antibiotics with fewer tooth loss (26% vs. 42%; $p = .019/.004$) and RBL ($p = .014/.024$) and mean probing pocket depth (PPD) at T1 ($p < .001$) with more tooth loss.

Conclusions: Subgingival instrumentation with adjunctive systemic antibiotics favours retention of class III furcation-involved teeth. Baseline RBL and PPD at T1 deteriorate long-term prognosis.

KEYWORDS
furcation involvement class III, long-term tooth survival, periodontitis stage III and IV, systemic antibiotics

Clinical Relevance

Scientific rationale for study: Regarding resective treatment of furcation-involved multi-rooted teeth, the 2019 European Workshop in Periodontology made recommendations for future research: for example, aggregation of raw data of existing studies to analyse the influence of factors besides class II and III furcation involvement (FI), and reporting the residual attachment of the remaining roots and the percentage of radiographically measurable bone loss (RBL), respectively. This retrospective study collected and analysed additional parameters beyond the class of FI exclusively for teeth with class III FI.

Principal findings: Ninety-eight teeth (37%) were lost during, on average, 9 years. Multivariate mixed models identified adjunctive systemic antibiotics to be associated with less and baseline RBL and mean probing pocket depth (PPD) at the start of supportive periodontal care (SPC) with more tooth loss.
Practical implications: When planning periodontal treatment of teeth with class III FI, RBL at baseline and PPD at start of SPC have to be taken into consideration besides FI.

1 | INTRODUCTION

The ultimate goal of dental/periodontal prevention and treatment is long-term retention of natural teeth in a healthy, functional, aesthetically acceptable, and painless state (Hirschfeld & Wasserman, 1978; Eickholz et al., 2008; Mombelli et al., 2014). Particularly in patients after periodontal treatment, attachment and tooth loss occur rarely (Graetz et al., 2020). However, attachment and tooth loss do not occur evenly in all patients but are more prevalent in a few so-called risk patients (Hirschfeld & Wasserman, 1978; Checchi et al., 2002). Many risk factors and indicators are already known. Patient-related risk factors are, for example, age, interleukin 1 polymorphism, smoking, irregular attendance at supportive periodontal care (SPC) (Eickholz et al., 2008; Pretzl et al., 2008; Muller et al., 2013; Lee et al., 2015), and individual biofilm control (Eickholz et al., 2008; Pretzl et al., 2008), and tooth-related risk factors are, for example, radiographic bone loss (RBL), furcation involvement (FI) (Dannewitz et al., 2006, 2016; Pretzl et al., 2008), and abutment tooth for fixed and removable dentures (Pretzl et al., 2008; Muller et al., 2013).

FI in a molar or premolar always represents a challenge for periodontal treatment. The furcation area is difficult and in some cases impossible to access and clean because furcation entrances are sometimes too narrow for instrumentation. In many cases, anatomical variations (e.g., root grooves, enamel projections, accessory root canals, and irregular surfaces) complicate treatment (DeSanctis & Murphy, 2000; Sanz & Giovannoli, 2000).

According to a meta-analysis, the relative risk of tooth loss due to FI during SPC is 1.46 (95% CI = 0.99–2.15, $p = .06$) in studies with up to 10 years of follow-up and 2.21 (95% CI = 1.79–2.74, $p < .0001$) in studies with 10–15 years of follow-up (Nibali et al., 2016). Eight percent of teeth with class I FI, 18% with class II FI, and 30% with class III FI were lost. In comparison to a molar with FI class I, a molar with FI class III carries a relative risk of 3.13 (95% CI = 2.30–4.24, $p < .0001$) for tooth loss (Nibali et al., 2016). Class II FI in mandibular molars and buccal of maxillary molars may be closed or transformed into class I FI (Jepsen et al., 2020) and regenerative treatment is recommended (Sanz et al., 2020). However, when looking into treatment options for class III FI [exclusive subgingival instrumentation (SI), open flap debridement (OFD), root resection, amputation, hemisection, tunnelling], the 2019 European Workshop in Periodontology did not find significant advantages for any treatment (Dommisch et al., 2020) and gave an open recommendation (Sanz et al., 2020). It was concluded that beyond the class of FI, additional factors such as, for example, RBL and residual pockets after treatment or the frequency of SPC may influence tooth survival. Thus, the workshop made recommendations for future research: for example, aggregation of raw data of existing studies to analyse the influence of factors besides class II and III FI, and reporting the residual attachment of the remaining roots and the percentage of radiographically measurable BL, respectively.

Only sparse data exist exclusively for teeth with class III FI. Thus, in this retrospective cohort study, we collected and analysed additional parameters beyond the class of FI exclusively for teeth with class III FI.

2 | MATERIAL AND METHODS

2.1 | Patients

All charts of patients who had undergone active periodontal therapy (APT) since October 2004 at the Center for Dentistry and Oral Medicine (Carolinum), Johann Wolfgang Goethe-University Frankfurt am Main, Germany, were screened for exhibiting teeth with class III FI. Patients' charts had to fulfil the following criteria:

- Systematic periodontal treatment not prior to October 2004 consisting of step 1 (supragingival biofilm and risk factor control), step 2 (SI in cases of aggressive or severe chronic periodontitis and detection of *Aggregatibacter actinomycetemcomitans* with adjunctive systemic antibiotics; Eickholz et al., 2013), and if required step 3 (surgical treatment). If *A. actinomycetemcomitans* had been detected, 500 mg amoxicillin and 400 mg metronidazole were prescribed three times daily for 7 days. In case of sensitivity to penicillin, 250 mg ciprofloxacin and 500 mg metronidazole were prescribed two times daily for 7 days (Griffiths et al., 2011; Feres et al., 2012);
- At least one tooth with class III FI (Hamp et al., 1975) prior to start of treatment;
- Complete periodontal charting with probing pocket depth (PPD) and vertical clinical attachment level (CAL-V) at six sites per tooth, FI (Hamp et al., 1975) at all furcation entrances of multi-rooted teeth prior to treatment (baseline, T0), and after completion of APT (re-evaluation 1 or 2 and start of SPC, T1). FI was exclusively assessed clinically using a Nabers probe (PQ2N, Hu-Friedy, Chicago, Illinois, USA);
- Radiographs of all teeth at T0;
- Follow-up ≥5 years after completion of APT (complete periodontal charting ≥5 years after accomplishment of APT, T2);
- SPC carried out at the Department of Periodontology of Goethe-University by dentists under postgraduate periodontal training or periodontal specialists in collaboration with dental nurses or dental

hygienists as well as by students under the respective dentists' supervision. SPC took place over the entire follow-up period according to the same structure (Eickholz et al., 2008; Petsos et al., 2020) and included the following items:

1. Modified GBI (Ainamo & Bay, 1975) and modified plaque control record (PCR; O'Leary et al., 1972);
2. Re-instruction and re-motivation for effective individual plaque control;
3. Professional mechanical plaque removal with hand instruments and polishing by use of rotating rubber cups with polishing paste (SuperPolish, Kerr GmbH, Biberach, Germany);
4. Application of fluoride gel (Elmex Gelee, GABA Schweiz AG, Therwil, Switzerland);
5. Twice a year, recording of a general dental examination and a complete periodontal status including PPD, BOP, FI, and tooth mobility test;
6. Once per year scoring of CAL-V and sensitivity testing;
7. At sites with PPD = 4 mm + BOP or PPD ≥5 mm, SI and instillation of 1% chlorhexidine digluconate gel (Chlorhexamed 1% gel, GlaxoSmithKline GmbH, Munich, Germany);
8. Patients scoring a high periodontal risk according to the periodontal risk assessment (Eickholz et al., 2008) and therefore scheduled four times a year received complete SPT including the above-mentioned items 1–5 in 6-month intervals and SPT without dental and periodontal status (items 1–4) in between;
9. If a patient exhibited >5 teeth with PPD ≥5 mm 2 years after re-evaluating the non-surgical or surgical approach, a recurrent systematic periodontal therapy was recommended considering individual factors such as the age of the patient, time of re-evaluation, and/or the presence of systemic diseases.

The trial was approved by the Institutional Review Board for Human Studies of the Medical Faculty of the Johann Wolfgang Goethe-University, Frankfurt/Main (174/19).

2.2 | Analysis of patient charts

For each patient, sex, age, and time of follow-up (T1 – T2) was extracted. Based on baseline examination, each patient was assigned a diagnosis (e.g., periodontitis, generalized stage III, grade B) according to the 2018 classification (Papapanou et al., 2018). The total number of SPC visits and regular SPC were assessed for each patient. If a patient did not violate the recommended SPC intervals by more than 100%, SPC was defined as regular. Violation of recommended intervals by more than 100% only once led to classification into irregular SPC [e.g., 6-month SPC interval is recommended but the patient returns after 13 months (Eickholz et al., 2008)]. The following data were extracted from the patient charts:

- Age at T0
- Smoking (active smoker, former smoker, non-smoker) (Lang & Tonetti, 2003) at T0
- Diabetes mellitus (T0)
- Root canal filling at tooth with class III FI (T0)
- Treatment of teeth with class III FI:
  - SI, OFD
  - Systemic antibiotics adjunctive to SI
  - resective treatment (root amputation, hemisection, trisection, root resection, tunnelling),
  - Type of roots resected
- Mean PCR (O'Leary et al., 1972) during SPC
- Mean PPD and CAL per tooth with class III FI at T0 and T1.

2.3 | Analysis of radiographs

Baseline radiographs (T0: panoramic or full sets of periapical intra-oral radiographs) were viewed on a screen in a darkened room (M.R.). The type of RBL was categorized into horizontal/vertical. Vertical RBLs (intra-bony defects) were measured and categorized into shallow (≤3 mm) and deep (>3 mm) using a scaled loupe (Peak No. 1983 Scale Lupe, 10×, Thokai Sangyo, Japan) (Eickholz et al., 1998).

Relative RBL (distance from the cemento–enamel junction to the alveolar crest in relation to root length) was assessed at the periodontally most affected site of each tooth with class III FI and at the tooth with most severe BL in the dentition (grade) using a Schei ruler with 10% scale (Schei et al., 1959). The most coronal line of the Schei ruler was oriented perpendicular to the tooth axis of the respective tooth and shifted horizontally until the most apical line touched the apex. Relative BL at the most severe inter-dental site of respective teeth in relation to the root length was assessed in 10% steps, always rounded to the next full 10% step. Division of relative RBL by patients' age provided the RBL age coefficient (Tonetti et al., 2018; Eickholz et al., 2020).

2.4 | Statistical analysis

The patient is defined as a statistical unit. The main outcome variable is tooth loss during SPC. All data were entered into an Excel data matrix (M.R.). Statistical analyses were performed using PC programs (Systat™ for Windows Version 13, Systat Inc. Evanston, Illinois; IBM® SPSS® Statistics 24 software package, IBM, Chicago, Illinois, USA; R version 4.0.2) (Team, 2021). For all individuals, cigarette pack years were calculated. Patient characteristics were described as absolute and relative frequencies (binomial and categorial variables) or means ± SDs (continuous variables). Variables were compared univariately (Chi-squared test for categorical variables and *t*-test for continuous variables) between the teeth retained and lost to identify possible independent variables for multivariate analysis. Univariate tests do not consider the clustered structure of the data.

Using logistic mixed-model regression and mixed Cox proportional hazard model, patient-related (adjunctive systemic antibiotics) and tooth-related (relative RBL at T0, mean PPD, and mean CAL at T1, vertical/horizontal bone loss [logistic] or deep [>3 mm] intra-bony pockets

TABLE 1 Patient characteristics

Total number	160	
Observation time (months) (mean ± SD; *M*, LQ/UQ)	109.0 ± 33.5	110, 78/137
Females [*n* (%)]	82 (51)	
Age (years, mean ± SD; *M*, LQ/UQ)	54.4 ± 9.8	54, 47/61
Diabetes [*n* (%)]	9 (6)	
Smoking		
Active smokers [*n* (%)]	39 (24)	
Non-smokers [*n* (%)]	84 (53)	
Former smokers [*n* (%)]	37 (23)	
Pack years (mean ± SD; *M*, LQ/UQ)	10.9 ± 17.9	0, 0/18
Adjunctive systemic antibiotics [*n* (%)]	38 (24)	
SPC		
Total number of SPC visits (mean ± SD; *M*, LQ/UQ)	19.8 ± 10.7	17.5, 13/24
Number of SPC visits per year (mean ± SD; *M*, LQ/UQ)	2.1 ± 0.8	2, 1.6/2.6
Regular SPC [*n* (%)]	66 (41)	

Abbreviations: LQ, lower quartile; M, median; SPC, supportive periodontal care; UQ, upper quartile.

TABLE 2 Diagnoses: Periodontitis according to stage and grade [*n* (%)]

Stage	Extent	Grade B	Grade C	Total
III	Localized	4 (3)	6 (4)	10 (7)
III	Generalized	31 (19)	44 (28)	75 (46.5)
IV	Generalized	24 (15)	51 (31)	75 (46.5)
Total		59 (37)	101 (63)	160

[Cox proportional hazard]) factors should be identified which are associated with tooth loss. The patient was included as a random effect to consider the clustered structure of teeth within patients. Since this is an explorative study, the *p*-values are descriptive in nature.

3 | RESULTS

3.1 | Patients

One-hundred and sixty patients presenting 265 multi-rooted teeth with class III FI were included in this analysis. Ninety-eight teeth (37%) were lost over a mean observation period of 110.0/78.0/137.0 (median/lower/upper quartile) months. Seven teeth were lost exclusively due to caries, 46 exclusively due to periodontal, 10 exclusively due to endodontal, and 8 exclusively due to prosthodontic reasons. Fifteen teeth were lost due to combined endodontal and periodontal reasons, three due to combined prosthodontic and periodontal, and one due to combined caries and prosthodontic reasons. For eight teeth, the reason for extraction could not be assessed.

The number of SPC visit ranged from 3 to 54. Table 1 provides the patient characteristics in detail. Eighty-five patients were diagnosed with stage III (10 localized, 75 generalized) and 75 with stage IV (generalized). Fifty-nine patients were assigned to grade B and 101 to grade C (Table 2).

Univariate comparisons between teeth retained and teeth lost with regard to patient characteristics (sex, stage, grade, smoking, regular/irregular SPC, systemic antibiotics adjunctive to SI) revealed only systemic antibiotic adjunctive to SI to indicate a statistically clear impact ($p = .013$) (Table 3). Comparison between teeth retained and lost regarding total number of SPC visits (retained 17/12/25; lost: 18/13/28; $p = .287$) and median SPC visits per year (retained 2.1/1.6/2.8; lost: 2/1.7/2.7; $p = .786$) failed to detect significant differences.

TABLE 3 Tooth loss according to patient characteristics [*n* (%)]

	Retained	Lost	*p*
Total (265)	167 (63)	98 (37)	
Male (134)	86 (64)	48 (36)	.692
Female (131)	81 (63)	50 (37)	
Generalized stage III (123)	81 (66)	42 (34)	.350
Generalized stage IV (131)	78 (60)	53 (40)	.246
Grade B (79)	53 (67)	26 (33)	.371
Grade C (186)	114 (61)	72 (39)	
Maxilla (175)	109 (62)	66 (38)	.730
Mandible (90)	58 (64)	32 (36)	
Current smoker (76)	49 (64)	27 (36)	.756
Former/never smoker (189)	118 (62)	71 (38)	
Regular SPC (115)	73 (63)	42 (37)	.892
Irregular SPC (150)	94 (63)	56 (37)	
Adjunctive systemic antibiotics (81)	60 (74)	21 (26)	.013
No adjunctive systemic antibiotics (184)	107 (58)	77 (42)	

TABLE 4 Distribution of teeth according to jaw and type [*n* (%)]

Total number		265		
Type	Premolar	First molar	Second molar	Third molar
Jaw	[2 (0.8)]	[153 (58)]	[106 (40)]	[4 (1.5)]
Maxilla [175 (66)]	2	105 (40)	68 (26)	0
Mandible [90 (34)]	0	48 (18)	38 (14)	4

TABLE 5 Tooth loss according to tooth characteristics [*n* (%)]

	Retained	Lost	*p* value
Total (265)	167 (63)	98 (37)	
Root canal filling (37)	21 (57)	16 (43)	.395
No root canal filling (228)	146 (64)	82 (36)	
Vertical bone loss (75)	36 (48)	39 (52)	.001
Horizontal bone loss (190)	131 (69)	59 (31)	
Radiographic bone loss at baseline (%)	47.9 ± 13.4	54.8 ± 14.9	<.001
Clinical attachment loss (baseline)	8.4 ± 2.1	9.3 ± 2.9	.004
Clinical attachment loss (start of SPC)	7.2 ± 2.1	8.7 ± 2.6	<.001
PPD (baseline)	7.2 ± 1.8	7.8 ± 2.4	.024
PPD (start of SPC)	5.0 ± 1.6	6.4 ± 2.1	<.001

TABLE 6 Tooth loss according to treatment [n (%)]

	Retained	Lost	*p* value
Total (265)	167 (63)	98 (37)	
Periodontitis therapy step 1 only (3)	2 (67)	1 (33)	1.000
SI (step 2) only (150)	86 (57)	64 (43)	.029
Additional periodontitis therapy step 3			
OFD (37)	30 (81)	7 (19)	.014
Tunnelling (24)[a]	19 (79)	5 (21)	.086
Resective furcation surgery (52)[a]	31 (60)	21 (40)	.571

[a]One maxillary molar with trisection, and tunnelling of remaining two roots.

3.2 | Teeth

A total of two maxillary first premolars and 263 molars (first: 153; second: 106; third: 4) with class III were included. One-hundred and seventy-five teeth were located in the maxilla and 90 in the mandible (Table 4). Data for one tooth were incomplete.

Univariate comparisons between teeth retained and lost with regard to tooth characteristics (root canal filling [yes/no], vertical bone loss [yes/no], relative RBL at T0, CAL at T0/T1, PPD at T0/T1) revealed more teeth with vertical bone loss ($p = .001$), more relative RBL at T0 ($p < .001$), more CAL at T0 ($p = .004$)/T1 ($p < .001$), deeper PPD at T0 ($p = .024$)/T1 ($p < .001$) in teeth lost than teeth retained (Table 5).

TABLE 7 Roots resected in resective treatment [*n* (%)]

	Retained	Lost	*p* value
Total (52)	31 (60)	21 (40)	
Root amputation (39)	22 (56)	17 (44)	.355
Trisection (4)	4 (100)	0	.300
Mesiobuccal root (9)	6 (67)	3 (33)	1.000
Distobuccal root (12)	8 (67)	4 (33)	1.000
Both buccal roots (5)	3 (60)	2 (40)	1.000
Palatal root (20)	10 (50)	10 (50)	.210
Hemisection (9)	5 (56)	4 (44)	.730
Mesial root (4)	1 (25)	3 (75)	.144
Distal root (5)	4 (80)	1 (20)	.654

3.3 | Treatment

Of a total of 265 teeth with class III FI, only 3 (1%) exclusively received step 1 periodontal treatment (i.e., oral hygiene instructions and risk factor modification) and SPC. One-hundred and fifty teeth received step 1 and 2 treatment (SI) and SPC. Further 113 teeth received additional step 3 treatment (periodontal surgery; open flao debridement (OFD): 37, tunnelling: 24, resective furcation surgery:

TABLE 8 Logistic mixed-model regression to explain tooth loss ($n = 264$)

	Odds ratio	Lower confidence level	Upper confidence level	*p* value
Relative radiographic bone loss (T0)	1.053	1.015	1.110	.014
Mean PPD (T1)	3.098	1.784	6.649	<.001
Mean CAL (T1)	0.931	0.612	1.423	.722
Vertical bone loss	1.627	0.64	4.492	.304
Systemic antibiotics	0.248	0.056	0.712	.019

TABLE 9 Cox proportional hazards mixed-model regression to explain tooth loss ($n = 264$)

	Hazard ratio	Lower confidence level	Upper confidence level	*p* value
Relative radiographic bone loss (BL; T0)	1.025	1.003	1.047	.024
Mean PPD (T1)	1.717	1.297	2.273	<.001
Mean CAL (T1)	0.929	0.74	1.167	.530
Deep intra-bony defects	1.672	0.928	3.011	.087
Systemic antibiotics	0.403	0.217	0.748	.004

52). Univariate comparisons between teeth retained and lost with regard to treatment revealed exclusive SI to result in more tooth loss ($p = .029$), whereas OFD resulted in more retention ($p = .014$) (Table 6). Resective furcation surgery encompassed 39 root amputations, 4 trisections and 9 hemisections. The distribution of resected roots is provided in Table 7.

SI and SPC were provided in part by dental students under supervision of postgraduate dentists under training for the specialist in periodontology of the German Society of Periodontology (DG PARO) and certified specialists and in part by postgraduate dentists and certified specialists themselves. Periodontal surgery was performed exclusively by postgraduate dentists and certified specialists. Indication for surgery was decided in consultation with the head of department (Peter Eickholz) or his deputy.

Logistic mixed-model regression identified adjunctive systemic antibiotics with less (26% vs. 42%; $p = .019$) tooth loss and RBL ($p = .014$) as well as mean PPD at T1 ($p < .001$) with more tooth loss (Table 8). Mixed Cox proportional hazard model associated adjunctive systemic antibiotics with less (26% vs. 42%; $p = .004$) tooth loss and RBL ($p = .024$) as well as mean PPD at T1 ($p < .001$) with more tooth loss (Table 9). Patients treated with systemic antibiotics (AB) were on average 4.6 years younger than those treated without (AB: 50.1 ± 10.6; no AB: 54.7 ± 0.2 years; $p = .005$). Both groups failed to show significant differences with regard to mean PPD after APT (T1) (AB: 3.7 ± 1.1 mm; no AB: 3.7 ± 1.8 mm; $p = .772$).

4 | DISCUSSION

The objective of this retrospective cohort study was the evaluation of survival of teeth with class III FI at least 5 years after APT and identification of prognostic factors. All charts of patients who had undergone APT at the Department of Periodontology of Goethe-University Frankfurt, Germany, beginning October 2004 were screened for teeth with class III FI. Charts were analysed for data of class III FI teeth at baseline (T0), at accomplishment of APT (T1), and at last SPC (T2). Further, baseline RBL and treatment were assessed. One-hundred and sixty patients suffering from severe periodontitis (85 stage III, 75 stage IV, 59 grade B, 101 grade C) presented with 265 teeth with class III FI. Ninety-eight teeth (37%) were lost during 109.0 ± 33.5 months. Systemic antibiotics adjunctive to SI was associated with less (26% vs. 42%) tooth loss and RBL as well as mean PPD at T1 with more tooth loss. SI with adjunctive systemic antibiotics seems to favour retention of class III furcation-involved teeth. Baseline RBL and PPD at T1 seem to deteriorate long-term prognosis.

Molars with class I FI have an approximately 50% increased risk for tooth loss up to 10 years and approximately 100% for more than 10 years after active periodontal treatment compared to molars without FI (Nibali et al., 2016). Molars with class II and III FI carry a substantially higher risk for tooth loss (Salvi et al., 2014; Graetz et al., 2015; Dannewitz et al., 2016). In comparison to a molar with FI class I, a molar with FI class II exhibits a relative risk of 1.67 and with class III of 3.13 for tooth loss (Nibali et al., 2016). Tooth loss rates for molars with class III FI vary between 25% (OFD) and 65% (resective furcation surgery) (Dommisch et al., 2020). Numerous randomized controlled trials (RCTs) have compared OFD and regenerative treatment in class II FI in mandibular molars and buccal of maxillary molars, providing solid evidence for closure or transformation into class I FI (Jepsen et al., 2020). Thus, regenerative treatment is recommended for this condition (Sanz et al., 2020). However, when looking into treatment options for class III FI (exclusive SI, OFD, root resection, amputation, hemisection, tunnelling), the 2019 European Workshop in Periodontology did not find any RCTs. Thus, the respective structured review (SR) had to rely on six retrospective and one prospective cohort studies. Six-hundred and sixty-seven patients presented 2021 teeth with class II or III FI. Data were very heterogeneous regarding

follow-up and distribution of FI. A total of 1515 teeth with class II and III FI survived 4–30.8 years after therapy. Survival ranged from 38% to 94.4% (root amputation or resection, root separation), from 62% to 67% (tunnelling), from 63% to 85% (OFD), and from 68% to 80% (SRP). Overall, treatment provided better results for class II FI than class III (Dommisch et al., 2020). The SR failed to identify significant advantages for any treatment (Dommisch et al., 2020) and gave an open recommendation (Sanz et al., 2020). It was concluded that beyond the class of FI, additional factors such as, for example, RBL and PPDs after treatment or SPC may influence tooth survival (Dommisch et al., 2020).

This study limited analysis to teeth with class III FI because a recent SR reported that periodontal treatment resulted in better survival in class II than in class III FI (Dommisch et al., 2020). Thus, the class of FI was excluded as a differentiating factor in this analysis. This study confirmed the assumption that baseline relative RBL and mean PPD at start of SPC (T1) have an effect on tooth survival. Baseline RBL is a risk factor for tooth loss in general (Pretzl et al., 2008) and molars in particular with FI (Dannewitz et al., 2006; Park et al., 2009; Graetz et al., 2015; Dannewitz et al., 2016; Tonetti et al., 2017). Another established parameter influencing tooth loss is residual pockets at the start of SPC (Kaldahl et al., 1996; Matuliene et al., 2008). In severe periodontitis, adjunctive use of systemic antibiotics has been shown to result in fewer residual pockets and less further attachment loss (Feres et al., 2012; Harks et al., 2015; Eickholz et al., 2019; Herrera et al., 2020). However, this is not supported by the comparison of mean PPD at teeth with class III FI at T1. On the other hand, systemic antibiotics have failed to reduce FI compared to placebo (Eickholz et al., 2016). Thus, the fact that systemic antibiotics adjunctive to SI were associated with enhanced tooth survival likely results from fewer residual pockets also in teeth with class III FI. For a good long-term prognosis, teeth with class III FI require a minimum of bone support (≥50%; Park et al., 2009) and should not exhibit residual pockets at the start of SPC. Based on univariate comparison, OFD had a beneficial effect on survival of teeth with class III FI (Table 6). We calculated different multivariate models using those variables that showed significant effects in univariate analysis. However, comparing the different models, systemic antibiotics had the strongest effect. Thus, OFD does not appear in the final model.

The Department of Periodontology of Goethe-University restricted systemic antibiotics to cases of aggressive or severe chronic periodontitis (now stage III and IV, grade C) and until 2018 only in patients with subgingival detection of *A. actinomycetemcomitans* (Eickholz et al., 2013). Despite the observation that in those cases teeth with class III FI benefitted from systemic antibiotics, a tooth with class III FI alone is not an indication for systemic antibiotics (Sanz et al., 2020).

One-hundred and fifty out of a total of 265 teeth with class III FI (57%) received only SI as active treatment. This treatment performs worse than the different surgical approaches. Why were not more teeth with class III FI treated surgically? Despite the clinical parameters, the strategic value of a respective tooth and the willingness of a patient to undergo surgery influence the decision for treatment. A second maxillary molar in a complete dentition of 28 teeth has less significance with regard to mastication than the same tooth adjacent to a gap and intended to serve as an abutment tooth. In the first case, SI may be rendered as a kind of less invasive "palliative treatment" with a good chance of retention for a while (Dannewitz et al., 2006). If this tooth is finally lost, mastication is not compromised. In the second case, rehabilitation of mastication by a fixed denture will rely on retention of the tooth, and the dentist and patient will consider more invasive treatment. The parameter of strategic significance is difficult to consider in this kind of analysis.

This study did not observe that sex, baseline diagnosis (stage, grade), smoking, and regular SPC affected survival of teeth with class III FI. Analysing survival of teeth with class III FI clinical parameters of the respective tooth may have higher significance than overall diagnosis. Owing to the fact that all patients by definition had to exhibit at least on tooth with class III FI, all patients were assigned at least to localized stage III (complexity: class II and III FI) (Tonetti et al., 2018). Thus, there were no big differences with regard to the stage between patients. Assignment of the grade may be due to BL at a tooth different from the tooth with class III FI. Thus, grade may be determined independently from the tooth with class III FI and less relevant for its prognosis. Nobody will doubt the general benefit of regular SPC for tooth survival (Lee et al., 2015). However, this study did not find an effect on survival of teeth with class III FI. This may be due to the fact that all patients attended SPC. However, only 41% attended regularly with an average of 2.1 ± 0.8 visits per year.

What are the limitations of this analysis? First of all, this is a retrospective cohort study with a high risk of bias. When looking into different types of resective furcation treatment, groups become quite small and analysis tends to be underpowered. Future studies may prospectively collect data from several centres to overcome the low test power.

Within the limitations of the present study, the following conclusions regarding periodontal treatment of teeth with class III FI may be drawn:

- SI with adjunctive systemic antibiotics favours retention of teeth with class III FI.
- Baseline RBL and PPD at the start of SPC seem to deteriorate long-term prognosis.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed substantially to the interpretation of the data for the work and to drafting and critically revising the manuscript. They gave their final approval of the version to be published and agreed to be accountable for all aspects of the work. Additionally, Peter Eickholz and B. Dannewitz contributed to the concept and design of the study; Maren Runschke collected the data; Katrin Nickles and Hari Petsos supervised methodical approaches; Bernadette Pretzl and Dorothea Kronsteiner analysed data, secured

funding, and managed the group; and Peter Eickholz led the writing.

ETHICS STATEMENT

The trial was approved by the Institutional Review Board for Human Studies of the Medical Faculty of the Johann Wolfgang Goethe-University Frankfurt/Main (174/19).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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