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SYSTEMATIC REVIEW

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Resective surgery for the treatment of furcation involvement: A systematic review

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Abstract

Objective: To evaluate the benefit of resective surgical periodontal therapy (root amputation or resection, root separation, tunnelling) in periodontitis patients exhibiting class II and III furcation involvement (FI) compared with non-surgical treatment (SRP) or open flap debridement (OFD).

Material: Outcomes were tooth survival (primary), vertical probing attachment gain, and reduction in probing pocket depth (secondary) evidenced by randomized clinical trials, prospective and retrospective cohort studies and case series with ≥ 12 months of follow-up. Search was performed on 3 electronic databases from January 1998 to December 2018.

Results: From a total of 683 articles, 66 studies were identified for full-text analysis and 7 studies finally included. Six hundred sixty-seven patients contributed 2,021 teeth with class II or III FI. Data were very heterogeneous regarding follow-up and distribution of FI. A total of 1,515 teeth survived 4 to 30.8 years after therapy. Survival ranged from 38%–94.4% (root amputation or resection, root separation), 62%–67% (tunnelling), 63%–85% (OFD) and 68%–80% (SRP). Overall, treatment provided better results for class II FI than class III.

Conclusion: Within their limits, the data indicate that in class II and III FI, SRP and OFD may result in similar survival rates as root amputation/resection, root separation or tunnelling.

KEYWORDS

furcation involvement, long-term survival, periodontitis, resective surgery

1 | INTRODUCTION

In multi-rooted teeth, periodontitis leads to periodontal destruction not only vertically but also horizontally between the roots creating furcation involvement (FI). Furcation-involved molars are at greater risk for further attachment loss than teeth without furcation involvement (Loos, Nylund, Claffey, & Egelberg, 1989; Nordland et al., 1987; Wang, Burgett, Shyr, & Ramfjord, 1994). They exhibit a higher risk for tooth loss than molars without furcation involvement or single-rooted teeth (Helal et al., 2019; Matuliene et al., 2008; Pretzl, Kaltschmitt, Kim, Reitmeir, & Eickholz, 2008). The prognosis of furcation-involved teeth depends on the degree of FI and the amount of residual attachment. While molars with class I FI show a similar prognosis as molars without FI, class II and III (Eickholz & Walter, 2018; Hamp, Nyman, & Lindhe, 1975) involved molars exhibit a significantly and clinically relevantly higher risk for tooth loss (Dannewitz, Krieger, Husing, & Eickholz, 2006; Dannewitz et al., 2016; De Beule, Alsaadi, Peric, & Brecx, 2017; Graetz et al., 2015; Konig, Plagmann, Ruhling, & Kocher, 2002; McGuire & Nunn, 1996b; Salvi et al., 2014). The current Classification of Periodontal and Peri-implant Diseases and Conditions considers class II and III FI and rates the respective

teeth as stage III (Tonetti, Greenwell, & Kornman, 2018). Thus, treatment approaches for the management of class II and III FI should lead to a reduced tooth loss.

Exploring frequency of FI in 9,689 individuals representative for the U.S. population, FI was scored. Partial FI was scored in sites where the explorer was definitely catching into but did not pass through the furcation representing degree I and degree II of the Hamp et al., 1975 classification (Hamp et al., 1975). Total furcation involvement was assigned when the explorer could be passed between the roots and through the entire furcation (degree III; Hamp et al. (1975)). The prevalence of through-and-through furcation involvement for all age groups was 0.9%, and the extent was 0.5% of posterior teeth per person. Further, the prevalence of furcation-involved teeth (through-and-through) increased with age (60 to 69 years: 2.1%; 70 to 79:3.2%; 80 to 89:3.4%) (Albandar, Brunelle, & Kingman, 1999). In a cohort of periodontitis patients, 28.5% of all molars exhibited class II or III FI, and 74% of all patients provided at least one molar with class II or III FI (Dannewitz et al., 2016). Particularly in periodontitis patients, class II and/or III FI occurs frequently.

Limited evidence suggests a conversion of class II FI into class I or 0 following regenerative therapy. However, there is no sufficient evidence from human clinical trials suggesting closure of through-and-through furcations by regenerative treatment (Sanz, Jepsen, Eickholz, & Jepsen, 2015). Thus, a resective surgical approach (root amputation or resection, root separation, tunnel preparation/tunnelling/tunnellization) becomes reasonable in cases with advanced FI.

The aim of the present systematic review was to assess the benefit of resective surgical treatment (root amputation or resection, root separation, tunnel preparation/tunnelling/tunnellization) of teeth with class II and III furcation involvement compared with non-surgical or open flap debridement.

Clinical Relevance

Scientific rationale for the this analysis: With regular periodontal care, molars with class I furcation involvement (FI) have a similar prognosis as molars without FI, whereas molars with class II and III FI exhibit a significantly higher risk for tooth loss. Thus, resective surgery is applied to improve long-term survival of these teeth.

Principal findings: The 7 included studies were rather heterogeneous with respect to factors beyond class II and III FI. Factors such as bone loss, jaw, smoking or periodontal maintenance were not regularly reported. Thus, in class II and III FI this review failed to show relevant differences in tooth survival 4 to 30.8 years after resective therapy compared to SRP and OFD.

Practical implication: The clinical decision for the choice of resective furcation surgery does not seem to be related to FI alone. Other factors such as amount of bone loss may play a role but could not be analysed based on the included studies. SRP and OFD resulted in class II FI in similar survival rates as resective treatment.

1.1 | Objective

A structured approach was used to formulate the research question for this systematic review using five components commonly known by the acronym "PICOS": the patient population (P), the interventions (I), the comparison group (C), the outcome of interest (O) and the study design (S). The respective PICOS components for this review are.

P: Subjects with periodontitis who have completed at least one cycle of non-surgical periodontal therapy and exhibit class II and III furcation involvement;

I: Resective surgical periodontal therapy (i.e. root amputation or resection, root separation, tunnel preparation/tunnelling/tunnellization);

C: No resective surgical periodontal therapy but not further treated, treated exclusively by subgingival debridement or access flap surgery;

O: 1) tooth survival (primary outcome), 2) vertical probing attachment (PAL-V) gain (secondary outcome), 3) reduction in probing pocket depth (PPD) (secondary outcome), 4) patient-related outcome measures (PROMs), possible adverse effects (AEs) and oral health-related quality of life;

S: Randomized controlled clinical trials, prospective and retrospective cohort studies and case series with at least 12 months of follow-up (survival, PAL-V, PPD).

The respective PICOS question was phrased as follows: What is the benefit of resective surgical periodontal therapy (i.e. root amputation or resection, root separation, tunnel preparation/tunnelling/tunnellization) in (I) subjects with periodontitis who have completed a cycle of non-surgical periodontal therapy and exhibit class II and III furcation involvement (P) compared to individuals suffering from periodontitis and exhibiting class II and III furcation involvement without resective surgical periodontal therapy but were not further treated, treated exclusively by subgingival debridement or access flap surgery (C) with respect to (a) tooth survival (primary outcome), (b) vertical probing attachment (PAL-V) gain, (c) reduction in probing pocket depth (PPD) and (d) patient-related outcome measures (PROMs), possible adverse effects and oral health-related quality of life (secondary outcomes) (O) evidenced by randomized controlled clinical trials, prospective and retrospective cohort studies and case series with at least 12 months of follow-up (survival, PAL-V, PPD) (S), respectively?

If no or only very few studies report results that provide answers to this PICOS question survival rates ≥ 12 months after resective periodontal surgery of class II and III FI will be listed and then compared with historical controls.

2 | MATERIAL AND METHODS

2.1 | Protocol development and eligibility criteria

A detailed protocol was designed according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement (Liberati et al., 2009; Moher, Liberati, Tetzlaff, & Altman, 2009). All authors reviewed and agreed on the protocol. Afterwards, it was submitted to and reviewed (January 2019) by the committee of XVI European Workshop on Periodontology as well as submitted to PROSPERO database (https://www.crd.york.ac.uk/prospero/).

Due to the fact that treatment paradigms have changed from the 20th to the 21st century (dentine adhesive direct composite restorations, less core and post indirect restorations, periodontal treatment standards i.e. start with non-surgical periodontal treatment), search was limited to articles published between January 1998 and December 2018.

2.2 | Information on sources and literature search

The search was performed on electronic databases from January 1998 to December 2018. The search was applied to PubMed, Scopus and Cochrane database for randomized controlled trials.

The applied strategy was a combination of MeSH terms and free-text words:

PubMed

Results: 383

Results (after removal of internal duplicates): **383**

("periodontal diseases" [MeSH Terms] OR "periodontitis" [MeSH Terms]) AND ("furcation" [All Fields] OR "furcation involvement" [All Fields] OR "interradicular lesions" [All Fields] OR "interradicular lesion" [All Fields] OR "root resection" [All Fields] OR "hemisection" [All Fields] OR "root amputation" [All Fields] OR "tunnel" [All Fields] OR "tunneling" [All Fields] OR "tunnel preparation" [All Fields] OR "tunnel procedure" [All Fields] OR "long-term maintenance" [All Fields]) AND ("molar" [All Fields] OR "molars" [All Fields] OR "multi-rooted" [All Fields] OR "multirooted" [All Fields]).

Filters activated: Publication date from 1998/01/01 to 2019/02/04.

Scopus

(https://www.scopus.com)

Results: 633

Results (after removal of internal duplicates): **632**

(KEY ("periodontal disease" OR "periodontitis")) AND (TITLE-ABS-KEY ("furcation" OR "furcation involvement" OR "interradicular lesions" OR "interradicular lesion" OR "root resection" OR "hemisection" OR "root amputation" OR "tunnel" OR "tunnelling" OR "tunnel preparation" OR "tunnel procedure" OR "long-term maintenance")) AND (ALL ("molar" OR "molars"OR "multi-rooted" OR "multirooted")).

AND PUBYEAR > 1997.

Cochrane database for randomized controlled trials.

(https://www.cochranelibrary.com/web/cochrane/advanced-search/search-manager).

Results: 39

Results (after removal of internal duplicates): **38.**

Upon literature search on the above-mentioned databases, selected original and review articles were thoroughly studied.

2.3 | Inclusion criteria

- Human studies
- Only subjects with periodontitis who have completed a cycle of non-surgical periodontal therapy.
- Studies reporting surgical resective treatment of teeth with class II or III FI in ≥ 20 patients suffering from periodontitis. If indication for surgical resective treatment was not provided by the article or data were not presented separately for indications, the authors were contacted to gain further information.
- Studies reporting no further, only non-surgical or open flap debridement treatment of teeth with class II or III FI in ≥ 20 patients suffering from periodontitis. If indication for treatment was not provided by the article or data are not presented separately for indications, the authors were contacted to gain further information.
- Follow-up of ≥ 12 months (survival, PAL-V gain, PPD reduction PROMs, AEs and oral health-related quality of life).
- Limited to English and German language.

2.4 | Exclusion criteria

- Case reports
- Studies reporting surgical resective treatment of endodontic lesions or caries.
- Studies that did not include non-surgical therapy prior to resective surgical therapy.
- No data on tooth survival and/or PPD reduction and/or PAL-V gain.
- No data on furcation involvement.

2.5 | Validity assessment

Two reviewers (P.E. and H.D.) independently screened titles, summaries and abstracts selected by electronic search. The inter-reviewer agreement was calculated by means of κ statistics (Landis & Koch, 1977). Publications of potential interest were then evaluated by full-text reading. The methodological quality assessment and data extraction of the included publications were independently conducted by two reviewers (B.D. and C.W.). Any disagreement was resolved by discussion among the two reviewers, including a third (P.E.) and a fourth reviewer (H.D.).

2.6 | Quality assessment of the included studies

Quality assessment was performed for all included studies (H.D.) according to items (registration, funding, randomization, blinding, participants, statistics, calibration, completeness of outcome data and other sources of bias) adopted from Graziani et al. (2012). Subsequently, the relative risk of bias was categorized by the following percentages: 0%-40%, high risk of bias; 40%-60%, considerable risk of bias; 60%-80%, moderate risk of bias; and 80%-100%, low risk of bias.

2.7 | Data analysis

The following information was retrieved from the publications:

Primary and secondary outcomes:

- Teeth with class II and III FI treated with surgical resective therapy (root resections, separations/tunneling):
  a. Survival after ≥ 12 months.
  b. PAL-V and PPD change after ≥ 12 months (if available).
  c. Any reported patient-related outcome measures (PROMs) and harm (e.g. PAL-V loss, root fracture) were listed.
- Teeth with class II and III FI treated without surgical resective therapy (scaling and root planing, subgingival debridement [no additional treatment], access flap):
  a. Number of teeth still present after ≥ 12 months.
  b. PAL-V and PPD change after ≥ 12 months (if available).
  c. Any reported patient-related outcome measures (PROMs) and harm (e.g. PAL-V loss, root fracture) was listed.

2.7.1 | Additional parameters

Obligatory:

- study design.
- year of publication.
- total number of subjects with class II and III FI.
- mean observation period.
- operator (university/practice).

Facultative:

- dropout rate.
- frequency distribution of class II and III furcations.
- age range, mean age (years) of subjects with class II and III FI.
- current sequence of periodontal treatment (i.e. non-surgical anti-infective therapy, re-evaluation, resective surgical treatment, SPT) (yes/no).
- mean number of teeth per patient at baseline and re-examination (total tooth loss over observation time as an estimate of periodontal stability).
- full mouth mean BOP at re-examination (as estimate of periodontal health).
- full mouth plaque score at re-examination (as estimate of oral hygiene).
- mean number of SPT visits per year.
- smoking history (number of current/never or former smokers).
- bone loss in % of root length at the retained roots.

Tables were generated accordingly. These factors were used to explain variation of tooth loss between individual studies. In case of missing data, authors were contacted for further information.

The Kappa statistic was used to assess inter-rater reliability between the two independent reviewers (Title/Abstract: H.D. and P.E.).

3 | RESULTS

This review is registered at PROSPERO (registration number: CRD42019123725).

3.1 | Study selection

A total of 683 studies were identified by electronic search. Hand searching did not identify additional articles for full-text analysis (Figure 1). Screening of titles and abstracts led to rejection of 617 articles. The examiners reached an agreement with a kappa score of 0.627 (fair to good agreement) (Landis & Koch, 1977). Full texts of the remaining 66 articles were then obtained. Subsequent to full-text analysis, certain corresponding authors (Carnevale, Pontoriero, & Febo, 1998; Dannewitz et al., 2006, 2016; Derks, Westheide, Pfefferle, Eickholz, & Dannewitz, 2018; Di Febo, Bedendo, Romano, Cairo, & Carnevale, 2015; Graetz et al., 2015; Hou, Tsai, & Weisgold, 1999; Konig et al., 2002; Salvi et al., 2014; Svardstrom & Wennstrom, 2000) were contacted for data clarification. This led to exclusion of further 59 articles [reasons for exclusion and list of excluded articles are depicted in (Table S1)]. Full texts of the remaining 7 articles were analysed for methodological quality and availability of data for meta-analyses.

3.2 | Quality assessment of the included studies

The proportion relevant for the determination of the potential relative risk of bias ranged between 53% and 91% (Table 1). While none of the included studies showed a high risk of bias, two were rated with a considerable risk of bias, three with a moderate risk of bias and two with a low risk of bias. As longitudinal and retrospective study designs were included, not all of the quality parameters were applicable. Four out of 7 studies made a statement on an ethical approval or signed informed consents. Due to the nature of resective periodontal surgery, blinding of patients, examiners and/or therapists was not applicable.

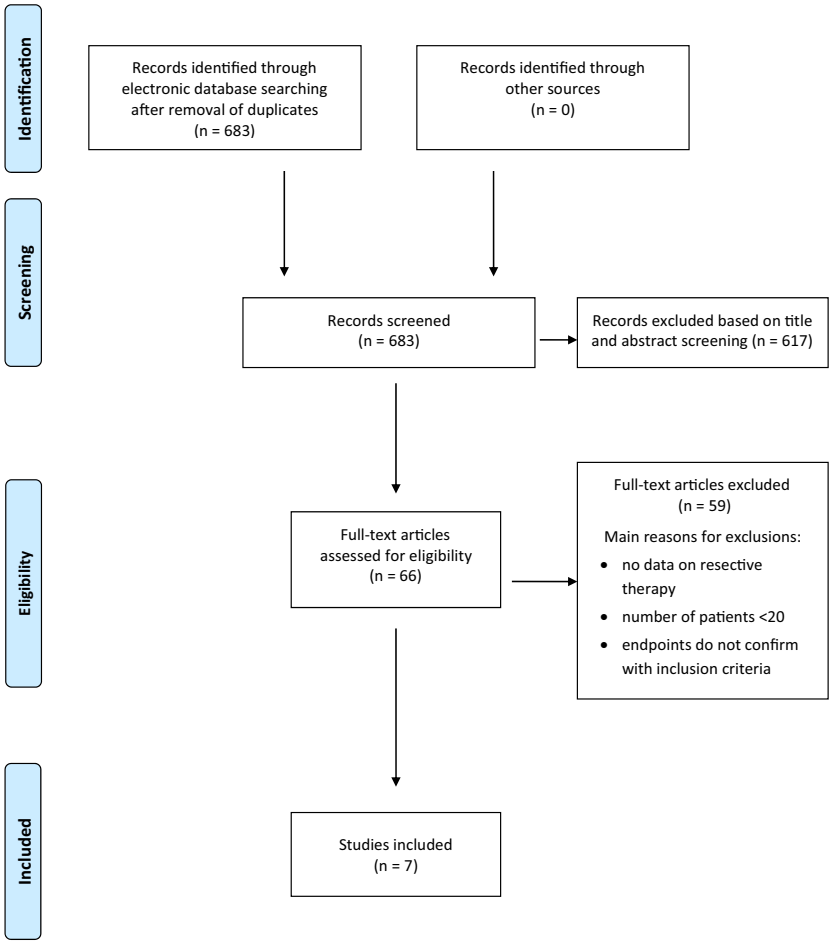

FIGURE 1 Flow chart screening and identification of publications [Colour figure can be viewed at wileyonlinelibrary.com]

Missing outcome data and reasons for dropouts were described in two studies, whereas inter-examiner calibration was not reported. Proper statistical analysis was performed in each included study. Information on further confounding factors was inconsistently reported among the studies included. In conclusion, the quality assessment revealed heterogenic degrees of bias, but no study was considered at high risk.

3.3 | Population

From a total of 683 articles, 66 studies were identified for full-text analysis and 7 studies were finally included. One prospective and 6 retrospective cohort studies and case series were included reporting a total of 667 patients contributing 2,021 teeth treated for class II and III FI. In some studies, resective surgery was also performed due to reasons different from class II and III FI (Carnevale et al., 1998; Derks et al., 2018). In these cases, the authors provided additional information on those teeth with class II and III FI. Four hundred forty-nine teeth were treated by root amputation or resection, root separation, 19 by tunnel preparation, 479 by OFD and 1,074 by SRP only. Whereas all studies referred to class II and III FI, not all provided the respective classification they referred to (Carnevale et al., 1998; Derks et al., 2018; Zafiropoulos et al., 2009). Three studies (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015) referred to the classification of FI according to Hamp et al. (1975) with one study using a modification (Graetz et al., 2015). One study applied an own definition for class II and III FI (Svardstrom & Wennstrom, 2000) (Tables 2–4).

While one study reported only treatment of class III FI (Zafiropoulos et al., 2009), the remaining studies included also patients contributing teeth with class II and III FI treated by resective surgery. The follow-up periods ranged from 4 to 30.8 years. The only prospective study reported a follow-up of 10 years for all patients. All other studies aggregated patients with different observation periods. Thus, results were summarized for all studies and separately for 3 categories of follow-up: studies including (a) only teeth with ≥ 10 years of follow-up, (b) teeth with ≥ 5 years but not only teeth with ≥ 10 years of follow-up and (c) teeth with ≥ 12 months but not only teeth with ≥ 5 years of follow-up (Tables 2–4). Four studies provided the results of resective treatment of class II and III FI as subsets of larger cohorts evaluating treatment of furcation involvement in general (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015; Svardstrom & Wennstrom, 2000). For these studies, the follow-up periods for the respectively treated teeth could not be retrieved separately.

3.4 | Intervention

Resective periodontal surgery (root amputation or resection, root separation, tunnel preparation) in subjects with periodontitis who

had completed a cycle of non-surgical periodontal therapy and exhibited class II and III FI was included in this systematic review. Techniques for resective periodontal surgery showed variations among the selected studies. Carnevale et al. rendered root amputation or resection and root separation in teeth with class II or III FI explicitly always with osseous recontouring and apically positioned flaps (Carnevale et al., 1998). Further, 84 of these teeth were used as abutments for fixed partial dentures. In 3 studies, all patients had been treated surgically by the same therapist (De Beule et al., 2017; Derks et al., 2018; Zafiropoulos et al., 2009). For the remaining studies, it was unclear how many therapists were involved. Graetz et al. (2015) mentioned a whole group of therapists whose patients were included. Zafiropoulos et al. rendered only hemisection to mandibular molars. The extraction sockets of the resected roots were augmented with deproteinized bovine bone mineral mixed with autologous bone and covered by a biodegradable membrane (Zafiropoulos et al., 2009). Derks et al. (2018) performed flap elevation and osteotomy if needed. In severe cases, however, roots were also resected without flap elevation. Several studies mentioned that resective surgery was performed, but lacked detailed information (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015; Svardstrom & Wennstrom, 2000).

3.5 | Comparison

Five studies reported some sort of control treatment: osseous recontouring, apically positioned flaps at posterior teeth without furcation involvement (Carnevale et al., 1998), extraction and implant placement (Zafiropoulos et al., 2009), non-surgical treatment (SRP) or open flap debridement (OFD) (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015) (Tables 2 and 3).

Carnevale et al. (1998) reported a 99% tooth survival rate upon apically repositioned flap surgery with osseous recontouring around teeth without FI compared with a 94.4% tooth survival rate upon resective periodontal surgery on teeth with class II and III FI over a follow-up time period of 10 years (Table 2).

Zafiropoulos et al. (2009) observed a 97% implant survival rate following tooth extraction of class III FI and ridge preservation over a time period of 4.8 to 6.7 years. In contrast, a 79% tooth survival rate was recorded upon hemisection of mandibular molars with class III FI over 4 to 7.8 years (Table 4).

For an observation time of 9 to 30.8 years, three studies described results for teeth with class II and III FI (1,553 teeth) treated by SRP (1,074 teeth) and OFD (479 teeth) (Tables 2 and 3). Graetz et al. (2015) observed 69% survival after SRP of class II and III FI and 63% survival after OFD. Dannewitz et al. (2016) reported a tooth survival rate of 78% following SRP and 85% following OFD, respectively. De Beule et al. (2017) reported a tooth survival rate of 80% after single SRP, 68% after repeated SRP, and 84% following OFD. All 3 studies reported higher tooth survival rates in class II than in class III FI (Tables 2 and 3).

3.6 | Observation: Synthesis of data

Tooth loss represents the only variable that was provided by all studies. A total of 449 teeth with class II or III FI were treated by root amputation or resection or root separation. A total of 105 of these teeth were lost (23%) representing an average tooth survival rate of 77% over a time period of at least 4 years (Figure 2). There was a great variety of tooth survival ranging from 94.4% (Carnevale et al., 1998) to 38% (Dannewitz et al., 2016). For those studies reporting tooth loss for class II and III FI separately (Dannewitz et al., 2016; De Beule et al., 2017; Derks et al., 2018; Graetz et al., 2015), the survival rates were better for class II than class III FI (Tables 2–4). Tooth survival rates upon root amputation, resection and/or root separation were reported for all 3 follow-up categories separately: (a) 187 of 234 teeth with ≥ 10 years of follow-up: (80%), (b) 64 of 82 teeth with ≥ 5 years but not teeth with only ≥ 10 years of follow-up: (78%) and (c) 93 of 133 teeth with ≥ 12 months but not teeth with only ≥ 5 years of follow-up: (70%) (Tables 2–4).

Nineteen teeth with class II or III FI were treated by tunnel preparation. Of these, 7 teeth were lost (37%) representing an average survival rate of 63% during the analysed time period (only teeth with ≥ 10 years of follow-up) (Table 2).

Three studies also reported tooth loss after non-surgical therapy and OFD of 1,074 and 479 teeth, respectively, exhibiting class II and III FI. After SRP and OFD, 248 (23%) and 146 (30%), respectively, teeth were lost (Tables 2 and 3). These tooth loss rates were comparable to rates described for root amputation, resection and separation, and the overall tooth survival was greater when compared to tunnel preparation.

Four studies also report reasons for tooth loss (Carnevale et al., 1998; Derks et al., 2018; Svardstrom & Wennstrom, 2000; Zafiropoulos et al., 2009). Ten teeth were extracted due to root fractures, 12 due to caries, 11 due to endodontic complications, 18 due to periodontal disease and 2 due to other reasons (Tables 2–4).

The secondary outcome variable PAL-V gain was reported by one study (Zafiropoulos et al., 2009). PPD reduction was presented by two of the included studies (Carnevale et al., 1998; De Beule et al., 2017). While two studies provided frequencies of PPD (Carnevale et al., 1998; De Beule et al., 2017), the other provided PAL gain means ± standard deviation (Zafiropoulos et al., 2009). All remaining studies did not record PPD and PAL at all or not for class II and III FI separately (Graetz et al., 2015; Svardstrom & Wennstrom, 2000). The respective data are presented in Table 5. Due to variable presentation of the data provided, PPD and PAL could not be subjected to further analysis. Further, calculation of a weighted treatment effect (pre-operative–postoperative) was not possible.

Patient-related outcome measures (PROMs; e.g. postsurgical pain) or harm (e.g. root caries) after tunnel preparation (Hamp et al., 1975; Hellden, Elliot, Steffensen, & Steffensen, 1989) as addition to tooth loss or attachment loss was not reported by those studies included in this review. Zafiropoulos et al. (2009) reported not only tooth loss (non-salvageable complications; Tables 2–4) but also 6 salvageable complications without providing details.

TABLE 1 Risk of bias assessment of the included studies

Phase of the study	Item	Question	Answers	Carnevale et al. (1998)	Svardstrom & Wennstrom (2000)	Zafiropoulos et al. (2009)	Graetz et al. (2015)	Dannewitz et al. (2016)	De Beule et al. (2017)	Derks et al. (2018)
Registration	Ethic committee	Done?	0 = no/NR; 1 = yes	0	0	0	1	1	0	1
	Informed consent	Done?	0 = no/NR; 1 = yes	0	0	1	N.A	N.A	N.A	N.A
Funding	Independent funding	Described?	0 = private/industry/NR; 1 = university/government/self	0	1	1	1	1	1	1
Randomization	Sequence generation	Done?	0 = inadequate/NR; 1 = adequate	N.A	N.A	N.A	N.A	N.A	N.A	N.A
	Allocation concealment	Done?	0 = inadequate/NR; 1 = adequate	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Blinding	Patient	Done?	0 = inadequate/NR; 1 = adequate	N.A	N.A	N.A	N.A	N.A	N.A	N.A
	Examiner	Done?	0 = inadequate/NR; 1 = adequate	N.A	N.A	N.A	N.A	N.A	N.A	N.A
	Therapist	Done?	0 = inadequate/NR; 1 = adequate	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Participants	Clear definition of eligibility criteria	Described?	0 = no; 1 = yes	1	1	1	1	1	1	1
Statistics	Appropriate statistical analysis	Done?	0 = no/NR; 1 = yes	1	1	1	1	1	1	1
Calibration	Calibration	Done?	0 = no/NR; 1 = yes	0	0	0	N.A	N.A	N.A	N.A
Completeness of outcome data	Sample size calculation and power analysis	Done?	0 = no/NR; 1 = yes	N.A	N.A	N.A	N.A	N.A	N.A	N.A
	Missing outcome data reported	Reported?	0 = no; 1 = yes/no dropouts	1	1	N.A	N.A	N.A	N.A	N.A
	Reasons for dropouts specified	Reported?	0 = no; 1 = yes	1	1	N.A	N.A	N.A	N.A	N.A

(Continues)

TABLE 1 (Continued)

Phase of the study	Item	Question	Answers	Carnevale et al. (1998)	Svardstrom & Wennstrom (2000)	Zafiropoulos et al. (2009)	Graetz et al. (2015)	Dannewitz et al. (2016)	De Beule et al. (2017)	Derks et al. (2018)
Other sources of bias	Were systemic diseases and medication reported?	Reported?	0 = no; 1 = yes	1	0	1	1	1	0	0
	Were clinical periodontal conditions specified?	Reported?	0 = no; 1 = yes	1	1	1	1	1	1	1
	Was smoking reported?	Reported?	0 = no; 1 = yes	0	0	1	1	1	0	0
	Were oral hygiene levels reported?	Reported?	0 = no; 1 = yes	1	1	1	0	1	0	0
	Were tooth types specified?	Reported?	0 = no; 1 = yes	1	1	1	1	1	1	1
	Was duration of perio-endo lesions reported?	Reported?	0 = no; 1 = yes	0	0	0	0	0	0	0
	Were information on therapist given?	Reported?	0 = no; 1 = yes	0	1	1	1	1	1	1
Proportion				53%	60%	77%	82%	91%	55%	64%
Risk of bias				Considerable	Moderate	Moderate	Low	Low	Considerable	Moderate

4 | DISCUSSION

This systematic review evaluated the effect of resective surgical periodontal therapy (root amputation or resection, root separation, tunnel preparation) in periodontitis patients exhibiting class II and III FI and its benefit when compared to non-surgical treatment or open flap debridement. From a total of 683 articles retrieved from 3 electronic databases, 66 studies were identified for full-text analysis. Finally, 7 studies were analysed for methodological quality and the results were presented descriptively. One prospective and 6 retrospective cohort studies and case series were included reporting 667 patients contributing 2,021 teeth with class II or III FI. Data were highly heterogeneous regarding follow-up and distribution of FI. A total of 1,515 teeth survived 4 to 30.8 years after therapy. Survival ranged from 38%–94.4% (root amputation or resection, root separation), 62%–67% (tunnel preparation), 63%–85% (OFD) and 68%–80% (SRP). Overall, any treatment provided better results for class II than class III FI.

Quality assessment was performed for each of the included studies, which were heterogeneous in terms of study design. To meet the individual study design and perform a high degree of comparable risk assessment, the analysis was carried out according to criteria proposed by Graziani et al. (2012). Alternatively, the Newcastle–Ottawa Scale for cohort studies may be applicable. However, heterogeneity of the 7 included studies (case series, longitudinal and cohort studies) did not allow a comparable analysis according to the NOS criteria (http//ohri.ca/programs/clinical_epidemiology/oxford.asp), and the strength of the inclusion criteria already addressed NOS items. Thus, quality assessment was performed by evaluating additional items as described by Graziani et al. including ethics, funding, statistics, calibration, confounding factors (systemic diseases, smoking), periodontal and endodontic issues, and the information on therapist.

Ten years ago, Huynh-Ba et al. published a systematic review on treatment of multi-rooted teeth with FI in general. They included studies with observation periods of at least 5 years and reporting tooth loss. The subset of studies reporting resective surgical periodontal therapy (root amputation or resection, root separation, tunnel preparation) was published between 1972 and 2006 (Huynh-Ba et al., 2009). Treatment paradigms have changed from the 20th to the 21st century (dentine adhesive direct composite restorations, less core and post indirect restorations, periodontal treatment standards, i.e. start with non-surgical periodontal treatment). Thus, this structured review limited the search of articles starting January 1998. Whereas Huynh-Ba et al. included treatment of FI, in general, this review focused on resective surgical periodontal therapy of class II and III FI. Huynh-Ba et al. included 10 studies reporting root amputation or resection, root separation as well as 3 studies on tunnel preparation. They reported resective therapy of 1,158 teeth (Huynh-Ba et al., 2009). This review reports resective therapy of 468 teeth with class II and III FI. If studies reported resective surgery also due to reasons other than class II and III FI, the present review tried to retrieve the respective information on class II and III FI from the authors (e.g. Carnevale et al., 1998) which was not possible in all

TABLE 2 Resective treatment of class II and III furcation involvement: parameters of studies included in the systematic review considering only teeth with ≥ 10 years of follow-up (number of patients and teeth, frequency of class II and III furcation involvement (FI), type of treatment, tooth loss, reasons for tooth loss)

Study	Study design	Test Control	Follow-up mean (±SD) (range)	No of patients, age range (mean±SD),	No of teeth (location)	N Class FI	Resective therapy, Indication, surgical procedure	Non-surgical PT	SPT	N Tooth loss (%)	Reasons for tooth loss
Carnevale et al. (1998)*	prospective	test: root separation and/or resection	10 yrs	65 (from a total of 72 patients, 21-62 yrs [42.7 yrs])	test: 161 premolars/molars (from a total of 175 (12 deep angular defects 2 endodontic lesions)	123 class II, 38 class III, no definition of class II and III FI provided	• root separation and/or resection • 161 class II and III FI • osseous recontouring and apically positioned flaps	OHI, full-mouth SRP, reevaluation after 1-3 mo	OHI, professional tooth cleaning, every 2-6 mo	test: 9 (5.6%)	test: 3 root caries, 3 periodontal disease, 2 root fracture, 1 endodontic complications,
		control: surgery without root resection			control: 175 contralateral posterior teeth	no FI				control: 2 (1.1%)	control: 1 periodontal disease, 1 cement washout
Dannewitz et al. (2016)*	retrospective	test: resective therapy, tunnel preparation	13.2±2.8 (10-20 yrs)	28 patients, 23.7-65.5 (50±11.5 yrs),	test: 39 molars (only molars treated during APT)	• resective therapy: 26; 9 class II, 17 class III • tunnel preparation: 13 class III	n.r.	OHI, full-mouth SRP, reevaluation after 3-6 mo	clinical measurements, PI, re-instrumentation of, sites with PPD ≥ 4mm and BOP ≥ 5mm, individually scheduled ≤ every 12 mo	• resective therapy: 16 (62%); 5 class II (56%), 11 class III (65%) • tunnel preparation 5 (38%)	n.r.
		control: SRP, OFD		83 patients, 23.7-66.2 (46.4±11.4 yrs),	control: 198 molars	• SRP: 130; 97 class II, 33 class III • OFD: 68; 55 class II, 13 class III				• SRP: 28 (22%); 19 class II (20%), 9 class III (27%) • OFD: 10 (15%); 4 class II (7%), 6 class III (46%)	n.r.
De Beule et al. (2017)*	retrospective	test: root amputation, tunnelization	16.5 (10-27 yrs)	44 patients	test: 53 molars	• root amputation: 47; 29 class II, 18 class III • tunnelization: 6; 3 class II, 3 class III	root amputation, hemisection or tunnelization	yes	mean frequency: 1.76±0.57 per yr	• root amputation: 22 (47%); 13 class II (45%), 9 class III (50%) • tunnelization: 2 (33%); 1 class II (33%), 1 class III (33%)	n.r.
		control: SRP only, repeated SRP, OFD		n.r.	control: 853 molars	• SRP only: 651; 569 class II, 82 class III • repeated SRP: 131; 109 class II, 22 class III • OFD: 71; 67 class II, 4 class III				• SRP only: 127 (20%); 94 class II (17%), 33 class III (40%) • repeated SRP: 42 (32%); 30 class II (28%), 12 class III (55%) • OFD: 11 (16%); 10 class II (15%), 1 class III (25%)	n.r.
Summary						• resective therapy: 234 • tunnelization: 19 • SRP: 912 • OFD: 139				• 47 (20%) • 7 (37%) • 197 (23%) • 21 (15%)	

Abbreviations: APT, active periodontal therapy; BOP, bleeding on probing; OFD, open flap debridement; n.r., not reported; mo, months; OHI, oral hygiene instructions; PPD, probing pocket depth; PT, periodontal therapy; *SD*, standard deviation; SPT, supportive periodontal treatment; SRP, scaling and root planning; yr/yrs, years/years

[a]Contacted for data clarification

TABLE 3 Resective treatment of class II and III furcation involvement: parameters of studies included in the systematic review considering only teeth with ≥ 5 but not only teeth ≥ 10 years of follow-up (number of patients and teeth, frequency of class II and III furcation involvement (FI), type of treatment, tooth loss, reasons for tooth loss)

Study	Study design	Test Control	Follow-up Mean (±SD) (range)	N Patients, age range (mean±SD),	N Teeth (location)	N Class FI	Resective therapy, Indication, surgical procedure	Non-surgical PT	SPT	N Tooth loss (%)	Reasons for tooth loss
Svardstöm & Wennström (2000)*	retrospective	no control	9.5 yrs (8.0-12.0 yrs)	43 patients	47 molars	47 class II or III	• root separation/resection, • FI, residual PPD	OHI, full- mouth SRP, reevaluation after 3 mo	individually designed PM by referring dentist 2 times/years	5 (11%)	4 root fractures, 1 n.r.
Graetz et al. (2015)[a]	retrospective	test: root resective therapy	18.3±5.5 yrs (9-30.8 yrs)	24 patients	test: 35 molars	• root resection therapy: 35; 7 class II, 28 class III	n.r.	full-mouth SRP, reevaluation after 3-6 mo	non-surgical or surgical subgingival debridement with/without subsequent systemic or local antibiotic therapy at sites with PPD ≥ 5 mm + BOP or PPD ≥ 6 mm with/without BOP every 3-12 mo (maximum delay of 12 mo accepted)	• root resective therapy: 13 (37%); 1 class II (14%), 12 class III (43%)	n.r.
		control: SRP		• SRP: 94 patients 69 patients 25 patients	control: 502 molars	• SRP: 162; 123 class II, 39 class III				• SRP: 51 (31%); 34 class II (28%), 17 class III (44%)	n.r.
		OFD		• OFD: 196 patients 127 patients 69 patients		• OFD: 340; 225 class II, 115 class III				• OFD: 125 (37%); 68 class II (30%), 57 class III (50%)	
						• resective therapy: 82 • SRP: 162 • OFD: 340				• 18 (22%) • 51 (31%) • 125 (37%)	

APT, active periodontal therapy; BOP, bleeding on probing; OFD, open flap debridement; n.r., not reported; mo, months; OHI, oral hygiene instructions; PPD, probing pocket depth; PT, periodontal therapy; SD, standard deviation; SPT, supportive periodontal treatment; SRP, scaling and root planning; yr/yrs, years/years

[a]Contacted for data clarification

cases e.g. (Konig, Plagmann, Langenfeld, & Kocher, 2001). The present systematic review represents the most recent available evidence on resective periodontal surgery, with respect to current periodontal treatment standards.

4.1 | Population

The population sampled in this systematic review is quite heterogeneous. This applies to the reported follow-up periods. Whereas the only prospective study reported a uniform follow-up period of 10 years (Carnevale et al., 1998), all other studies reported ranges of follow-up between 4 and 30.8 years. The longer the observation period, the higher is the risk for tooth loss (Pretzl, Sayed, Weber, Eickholz, & Baumer, 2018). By generating 3 categories of different follow-up ranges, this review tried to address this issue. Interestingly, for root amputation or resection and root separation survival rates were similar across the 3 categories (Tables 2–4). Moreover, 4 studies provided the results of resective treatment of class II and III FI as subsets of larger cohorts evaluating treatment of FI in general (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015; Svardstrom & Wennstrom, 2000). For these studies, the follow-up periods for the respectively treated teeth could not be retrieved separately. Thus, for these studies, neither the range nor the average of follow-up is known for the respectively treated teeth. Thus, a substantial amount of heterogeneity exists with regard to observation periods.

4.2 | Indication

All studies included in this systematic review referred to class II and/or III FI. However, not all provided the respective classification they referred to (Carnevale et al., 1998; Derks et al., 2018; Zafiropoulos et al., 2009). Three studies (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015) used the classification of FI according to Hamp et al. (1975) with one study applying a modification of this classification (Graetz et al., 2015). One study used an own definition of class II and III FI (Svardstrom & Wennstrom, 2000). Class III FI may be generally referred to as "through-and-through" FI (Eickholz & Walter, 2018; Hamp et al., 1975); that is, the whole attachment from one furcation opening to the opposite side of the tooth is destroyed. However, with Svardstrom & Wennström for a score/class II the tip of a curved probe passes horizontally the furcation entrance but did not reach to the centre of the furcation area and a score/class III means that the tip of a curved probe reaches to or beyond the centre of the furcation area (Svardstrom & Wennstrom, 2000). According to Graetz et al., a class III (through-and-through) furcation required to observe the tip of the Nabers probe at the contra-lateral furcation opening (Graetz et al., 2015). Thus, all class III FI assessed by Svardstrom & Wennstrom (Svardstrom & Wennstrom, 2000) where the tip of the curved probe could not be seen at the contra-lateral furcation opening would be class II FI when referred to Graetz et al. (2015). Several studies report different survival rates according to class of FI in particular with differences between class II and III (Dannewitz et al., 2016; Graetz et al., 2015; McGuire & Nunn, 1996a; Salvi et al., 2014). Thus, even discrete differences in classification of FI may cause heterogeneity of results between studies.

4.3 | Intervention

In all studies included in this systematic review, patients received oral hygiene instructions and non-surgical anti-infective treatment (i.e. subgingival debridement) prior to resective surgery. Practically, all studies published prior to 1998 did not follow this rationale or did not provide this information (e.g. Hellden et al., 1989). Thus, the literature search started from January 1998. Techniques for resective periodontal surgery exhibited variations among the selected studies. Carnevale et al. (1998) rendered root amputation or resection and root separation in 123 teeth with class II and only 38 with III FI explicitly combined with osseous recontouring and apically positioned flaps and most teeth then served as abutments for fixed partial dentures. In certain studies, all patients had been treated by the same therapist (De Beule et al., 2017; Derks et al., 2018; Zafiropoulos et al., 2009), whereas in the remaining studies, it was unclear how many therapists were involved (Graetz et al., 2015). Zafiropoulos et al. reported only hemisection of mandibular molars and augmentation of extraction sockets (Zafiropoulos et al., 2009). Several studies mention that resective surgery was performed. However, they did not go into detail (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015; Svardstrom & Wennstrom, 2000). Thus, there was considerable heterogeneity regarding surgical techniques and their individual indications.

Focusing on control treatments, the question may arise what the difference between OFD and tunnel preparation in molars with class III FI may be. A tunnel preparation intends to make the interradicular space/the furcation accessible to oral hygiene measures. Tunnel preparations frequently encompass osseous surgery to enlarge the interradicular space and apically repositioned flap procedures. In the case of OFD on a molar with class III FI, the respective tooth is instrumented after flap mobilization. Both procedures have different intentions. However, they may have the same result: access to the interradicular space for individual oral hygiene, which, by the way, may in some cases also result after SRP of a molar with class III FI if the soft tissue recedes apically to the furcation fornix (De Beule et al., 2017).

4.4 | Comparison

Five studies reported some sort of control treatment. Carnevale et al. (1998) compared root amputation or resection and root separation in teeth with class II or III FI with osseous recontouring and apically positioned flaps at posterior teeth without furcation involvement. Zafiropoulos et al. (2009) compared hemisection of mandibular molars with class III FI with extraction and implant placement. During

TABLE 4 Resective treatment of class II and III furcation involvement: parameters of studies included in the systematic review including also teeth ≥ 12 months but not only with ≥ 5 years of follow-up (number of patients and teeth, frequency of class II and III furcation involvement (FI), type of treatment, tooth loss, reasons for tooth loss)

Study	Study design	Test control	Follow-up Mean (±*SD*) (range)	No of patients, age range (mean ± *SD*)	No of teeth (location)	No of class FI
Zafiropoulos et al. (2009)	Retrospective	Test: hemisection	Test: 5.4 yrs (4.0–7.8 yrs)	Test: 32 patients, 35–73 yrs (49 yrs)	Test: 56 molars (mandibular first and second)	56 class III, no definition of class III FI provided
		Control: extraction and implant	Control: 5.4 yrs (4.8–6.7 yrs)	Control: 28 patients, 29–67 yrs (51 yrs)	Control: 36 implants (in the region of the mandibular first or second molar)	
Derks et al. (2018) [a]	Retrospective	No	14.7 ± 6.8yrs (4–30 yrs)	58 patients	77 molars	12 class II, 65 class III
						Resective therapy: 133

Abbreviations: APT, active periodontal therapy; BOP, bleeding on probing; OFD, open flap debridement; n.r, not reported; mo, months; OHI, oral hygiene instructions; PPD, probing pocket depth; PT, periodontal therapy; *SD*, standard deviation; SPT, supportive periodontal treatment; SRP, scaling and root planning; yr/yrs, years/years

[a]Contacted for data clarification.

follow-up, 21% of the hemisected teeth were lost. The survival rate of implants with 97% was better than for any other treatment. The control group of Carnevale et al., 1998 does not exhibit class II or III FI. The control group of Zafiropoulos et al., 2009 did not compare hemisection to SRP or OFD but implant placement. Thus, both control groups are irrelevant to this review.

Carnevale et al. report with 94.4% by far the best tooth survival rate for root amputation or resection and root separation. They treated 123 teeth with class II but only 38 with class III FI (Carnevale et al., 1998). Dannewitz et al. reported the worst tooth survival with 38% after root amputation or resection and root separation of 9 teeth with class II and 17 with class III FI (Dannewitz et al., 2016). In general, class II FI provided better tooth survival rates than class III FI (De Beule et al., 2017). This difference in frequency composition of furcation classes may have partially contributed to differences in tooth survival. Based on these findings, it may be speculated that molars with class II FI exhibit a higher degree of remaining attachment when compared to molars with class III FI. Resective therapy per se further reduces the amount of attachment around teeth so that it is conceivable that, upon resective surgery (amputation, resection, separation), a molar with class II FI will eventually present a higher degree of remaining attachment, and therewith, a greater tooth survival rate than molars with class III FI.

Graetz et al. have shown that beyond class of FI jaw may have an influence on the success of furcation treatment. Using multivariate analyses, they report a higher risk of tooth loss after furcation treatment in the maxilla than in the mandible (Graetz et al., 2015). Dannewitz et al. could not confirm this observation (Dannewitz et al., 2016). Tooth location (maxilla/mandible, first/second molar) may make a difference. However, most of the included studies did not report primary or secondary end points separately according to jaw and molar position, respectively. Thus, the respective putative effect could not be extracted.

Out of the 7 studies included, three further studies reported reasonable comparisons to resective therapy. They show results from 9 to 30.8 years after SRP (1,074) and OFD (479 teeth) of class II and III FI (1,553 teeth). Graetz et al. observed 69% survival after SRP and 63% survival after OFD (Graetz et al., 2015). Dannewitz et al. reported 78% survival after SRP and 85% survival after OFD (Dannewitz et al., 2016) and De Beule 80% survival after single SRP, 68% survival after repeated SRP and 84% survival after OFD (De Beule et al., 2017). All 3 studies reported better survival rates in class II than in class III FI (Tables 2–4). The survival rates of non-surgical treatment of class II FI as well as OFD of class II and III FI were similar to the overall survival rate of root amputation or resection, root separation of 77%. However, there was a great variety of tooth survival rates after root amputation/resection ranging from 94.4% (Carnevale et al., 1998) to 38% (Dannewitz et al., 2016). Carnevale et al. performed resective surgery at an early stage of disease, whereas Dannewitz et al. may have extended the indication for resective surgery and tooth retention too far (Dannewitz et al., 2016). For those studies reporting tooth loss for class II and III FI separately (Dannewitz et al., 2016; De Beule et al., 2017; Graetz et al., 2015), the survival rates in general were better for class II than class III FI. However, beyond class of FI, we do not have any other determinants of long-term success as bone loss, smoking, regularity of SPT or duration of follow-up. Thus,

Resective therapy, Indication, surgical procedure	Non-surgical PT	SPT	No of tooth loss (%)	Reasons for tooth loss
Hemisection (mesial root), full-thickness flap, extraction site filled with bovine-derived xenograft (BioOss) and autologous bone, covered with resorbable membrane (Bio-Gide), clindamycin 600 mg/day for 4 days, post-operative care twice a month during first 2 mo and 1x/mo for following 10 mo	Full-mouth SRP, subsequent periodontal surgery (≥ 6 mo before hemisection)	OHI, supra- and subgingival debridement, every 6 mo	Test: 12 (21%) Control: 1 (3%)	Test: 6 root caries, 2 apical abscess, 4 root fracture Control: n.r
• 5 root separation • 72 root separation and resection • Mucoperiosteal flap, osteotomy or osteoplasty if needed	Yes (only in patient affected by periodontal disease)	Dental and periodontal examinations ≤ every 12 mo OHI, mechanical plaque removal every 6 mo	• Resective therapy: 28; 3 class II (25%), 25 class III (38%) • 40 (30%)	3 root caries, 15 periodontal disease, 8 endodontic complications, 2 other reasons

a direct comparison between the results of different studies may be misleading. Taken together, the 3 studies providing comparisons to resective furcation therapy in molars show inconclusive results, with one study demonstrating similar results after root amputation, resection and/or root separation and SRP/OFD (Graetz et al., 2015) and two studies showing better survival rates for teeth treated by less invasive periodontal treatment approaches (Dannewitz et al., 2016; De Beule et al., 2017).

4.5 | Observation: Synthesis of results

Due to the observed heterogeneity between the studies (s.a.), a statistical meta-analysis was not appropriate and therefore was not performed. However, a descriptive synthesis of data was performed. A total of 105 teeth treated by root amputation or resection and root separation for class II or III FI were lost (23%). From 19 teeth with class II or III FI treated by tunnel preparation, 7 were lost (37%). Tunnel preparations exhibit a worse survival rate than root amputation, resection and/or separation. However, up to now, root amputation, resection and/or separation require root canal treatment and, thus, more effort and cost than tunnel preparations that can be performed at vital teeth. Thus, tunnel preparations may be an option particularly for vital mandibular molars with class III FI. However, in this context, it needs to be considered that, after tunnel preparation, teeth may be more prone to develop root caries within the tunnel (Hamp et al., 1975; Hellden et al., 1989).

Only 4 studies provide information about reasons for tooth loss/extraction (Carnevale et al., 1998; Derks et al., 2018; Svardstrom & Wennstrom, 2000; Zafiropoulos et al., 2009) (Tables 2–4). Obviously periodontal disease was not the most frequent reason for tooth loss. Root fractures and caries caused most extractions (Sanz et al., 2017).

Based on the aggregated data, we cannot state a benefit for resective treatment compared with SRP and OFD. Data comparing resective treatment to extraction and implant placement in the molar region as alternatives are even scarcer (Zafiropoulos et al., 2009). Molars with class II and/or class III FI are generally recognized as highly compromised teeth. Based on the findings in this systematic review, it became obvious that even those compromised teeth can be retained over a long time period. It was found that the analysed procedures, such as SRP, OFD and resective periodontal surgery, have an impact on tooth survival. In a patient with periodontitis, tooth retention by one of the aforementioned periodontal treatment strategies and a, therewith, postponed implant therapy may be the recommended therapeutic approach.

4.6 | Limitations

Beyond the degree of FI, several studies agreed in the significance of bone loss regarding success of treatment of furcation-involved teeth (Dannewitz et al., 2016; Graetz et al., 2015; Park, Shin, Yang, & Kye, 2009; Tonetti, Christiansen, & Cortellini, 2017). Aggregation of raw data of existing studies or future prospective studies may address

the amount of supporting bone left at the remaining roots after resective surgery as a factor contributing to prognosis and choice of treatment. A possible approach to assess the remaining circular residual bone of each molar root using CBCT three-dimensional imaging was suggested (Walter, Kaner, Berndt, Weiger, & Zitzmann, 2009; Walter, Schmidt, Dula, & Sculean, 2016). While such an imaging modality would provide the requested information, the increased radiation—just for study-related questions—needs to be carefully considered from an ethical perspective.

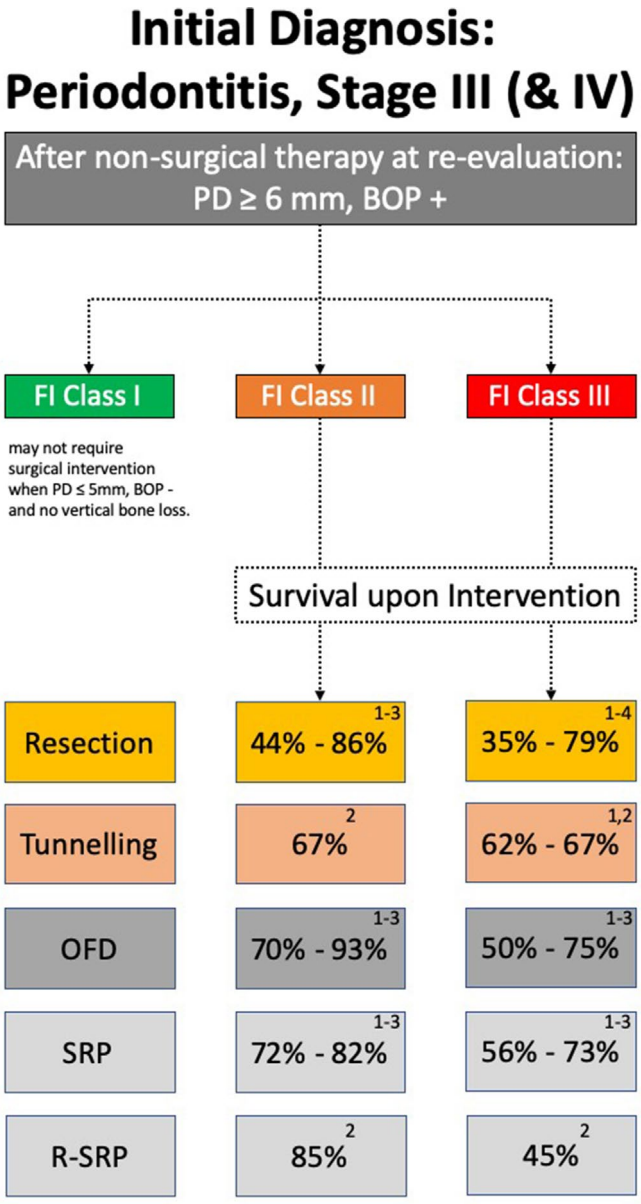

FIGURE 2 Tooth survival rates (in %) for the different treatment modalities in patients with class II and class III furcation involvement. Surgical approach: resection (root amputation, root resection, root separation, tunneling) and open flap debridement (OFD). Non-surgical approach: scaling and root planing (SRP) or repeated (R-)SRP. Data represent ranges of tooth survival. [1](Dannewitz et al., 2016); [2](De Beule et al., 2017); [3](Graetz et al., 2015); [4](Zafiropoulos et al., 2009) [Colour figure can be viewed at wileyonlinelibrary.com]

All included studies reported regular supportive periodontal therapy (SPT). SPT is the key factor for long-term tooth retention (Helal et al., 2019; Lee, Huang, Sun, & Karimbux, 2015; Pretzl et al., 2008). However, the SPT intervals between the different studies and between patients within the studies were substantially variable. These differences may have influenced the results of resective surgery and, thus, contribute to heterogeneity. The same applies to smoking. Smoking deteriorates long-term success of periodontal treatment in general (Eickholz, Kaltschmitt, Berbig, Reitmeir, & Pretzl, 2008) and particularly in molars (Dannewitz et al., 2016). However, we could not retrieve information on smoking on a patient level from the included studies to estimate the respective effect.

An ideal study on the effect of root amputation or resection, root separation or tunnelling in teeth with class II and/or III FI may be a prospective clinical trial with random assignment of resective surgery or some sort of control (e.g. non-surgical debridement). However, regarding long-term results on tooth loss this is a challenging task.

5 | CONCLUSION

With respect to the heterogeneity of included studies, the lack of RCTs, and based on the evidence aggregated in this systematic analysis of recent/timely studies on resective surgical periodontal therapy (root amputation or resection, root separation, tunnel preparation) in class II or III FI, an additional benefit of resective surgery compared with SRP or OFD in class II or III FI cannot be stated. However, in terms of elimination of periodontal inflammation, adjunctive surgical measures (root separation, root resection, tunnel preparation) may be yet justified. A careful case selection with respect to residual circular attachment is strongly suggested.

Most studies are lacking information on residual bone and attachment level after treatment of class II and III FI (baseline for follow-up), smoking, and intensity of SPT. Thus, these factors cannot be considered for comparison of treatments. None of the studies does report patient-related outcome measures (PROMs), adverse events, and/or oral health-related quality of life.

5.1 | Recommendations for future research

- Prospective study designs that include controls (e.g. only non-surgical treatment, OFD). Under ideal conditions with random treatment assignment.
- Aggregation of raw data of existing studies to analyse the influence of factors besides class II and III FI (e.g. vertical component of bone loss; e.g. Tonetti et al., 2017; SPT, smoking).
- Clear definition of classes of FI. Future studies may use a single classification (e.g. Eickholz & Walter, 2018; Hamp et al., 1975) or describe in detail the different classes of FI.
- Reporting the residual attachment of the remaining roots and the percentage of radiographically measurable bone loss, respectively.

TABLE 5 Probing pocket depth (PPD) and attachment level (PAL) change from prior to surgery to re-examination

Study	Before surgery/SRP	Re-examination	Before surgery/SRP	Re-examination
Carnevale et al. (1998)	Resective surgery class II and III FI (PPD)			
1–3 mm	0%	74%		
4–5 mm	30%	23%		
<5 mm	70%	3%		
	Posterior teeth without FI (PPD)			
1–3 mm	9%	92%		
4–5 mm	66%	6%		
< 5 mm	25%	2%		
De Beule et al. (2017)[a]	SRP only class II FI (number of teeth)		SRP only class III FI (number of teeth)	
≤ 3 mm	59	339	2	29
4–6 mm	365	129	44	18
≥ 7 mm	145	7	36	2
	Repeated SRP class II		Repeated SRP class III	
≤ 3 mm	9	45	4	6
4–6 mm	64	29	9	4
≥ 7 mm	36	5	9	0
	Open flap debridement class II		Open flap debridement class III	
≤ 3 mm	3	40	0	3
4–6 mm	46	15	3	0
≥ 7 mm	18	2	1	0
	Root amputation class II		Root amputation class III	
≤ 3 mm	1	6	1	5
4–6 mm	16	9	12	3
≥ 7 mm	12	1	5	1
	Tunnel preparation class II		Tunnel preparation class III	
≤ 3 mm	0	1	0	0
4–6 mm	2	1	3	2
≥ 7 mm	1	0	0	0
Study	First follow-up after hemisection	Re-examination	First follow-up after implant placement	Re-examination
Zafiropoulos et al. (2009)	Hemisection class III FI (PAL) Median (range)		Extraction and implant placement (PAL) Median (range)	
	5.5 (5.0, 6.0)	5.5 (4.5, 12.0)	3.8 (3.5, 7.8)	4.3 (3.8, 10.8)

[a]Discrepancies in number between prior to treatment and re-examination result from tooth loss.

- Reporting patient-related outcome measures (PROMs), adverse events and oral health-related quality of life.
- Existence and duration of periodontal–endodontal lesions.
- Reporting of tooth mobility.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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