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The effect of periodontal therapy on the survival rate and incidence of complications of multirooted teeth with furcation involvement after an observation period of at least 5 years: a systematic review

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Abstract

Objective: To systematically review the survival rate and incidence of complications of furcation-involved multirooted teeth following periodontal therapy after at least 5 years.

Material and methods: Electronic and manual searches were performed up to and including January 2008. Publication selection, data extraction and validity assessment were performed independently by three reviewers.

Results: Twenty-two publications met the inclusion criteria. Because of the heterogeneity of the data, a meta-analysis could not be performed. The survival rate of molars treated non-surgically was >90% after 5–9 years. The corresponding values for the different surgical procedures were:

Surgical therapy: 43.1% to 96%, observation period: 5–53 years.

Tunnelling procedures: 42.9% to 92.9%, observation period: 5–8 years.

Surgical resective procedures including amputation(s) and hemisections: 62% to 100%, observation period: 5–13 years.

Guided tissue regeneration (GTR): 83.3% to 100%, observation period: 5–12 years.

The most frequent complications included caries in the furcation area after tunnelling procedures and root fractures after root-resective procedures.

Conclusions: Good long-term survival rates (up to 100%) of multirooted teeth with furcation involvement were obtained following various therapeutic approaches. Initial furcation involvement (Degree I) could be successfully managed by non-surgical mechanical debridement. Vertical root fractures and endodontic failures were the most frequent complications observed following resective procedures.

Key words: furcation involvement; guided tissue regeneration (GTR); hemisection; non-surgical treatment; root resection; surgical treatment; tooth survival; tunnel

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The primary aetiology of periodontal diseases is the presence and maturation of a bacterial biofilm eliciting a host response (Socransky & Haffajee 2005). Treatment to arrest the development of such conditions involves subgingival mechanical debridement and establishment of a local environment for bacteria compatible with gingival health.

Studies have shown that chronic periodontitis may successfully be treated non-surgically and surgically. The maintenance of long-term favourable outcomes is warranted if adequate plaque control is maintained during the

supportive periodontal treatment phase (Axelsson et al. 2004). Because of their unique anatomical features, and their relative inaccessibility to professional (Fleischer et al. 1989) and self-performed (Lang et al. 1973) plaque control, multirooted teeth represent a challenge for the clinician. In periodontitis-susceptible patients, attachment loss may progress to such an extent that the furcation area becomes involved. Consequently, the loss of periodontal attachment develops in the horizontal directions and vertical in that area and is graded according to the classification of Hamp et al. (1975).

Findings from clinical studies have shown that furcation-involved molars respond less favourably to non-surgical periodontal therapy compared with molars without furcation involvement, and are more prone to further attachment loss (Nordland et al. 1987, Loos et al. 1989, Claffey & Egelberg 1994).

The poorer prognosis of furcation-involved teeth is further confirmed by longitudinal trials analysing the outcomes of periodontal therapy. Hirschfeld and Wasserman (1978) showed that over a 22-year period, patients enrolled in a supportive periodontal therapy (SPT) programme lost 7.1% of all teeth because of periodontal reasons. The corresponding figure for multirooted teeth with furcation involvement was 31%. Similar studies confirmed these findings (McFall 1982, Goldman et al. 1986).

A wide range of treatment modalities including non-surgical and surgical mechanical debridement, furcation plasty, tunnelling procedures, hemisections, root resections and regenerative procedures have been advocated to manage these particular anatomic areas.

Evidence documenting the survival and complication rates of furcation-involved teeth has not yet been assessed systematically. Therefore, the aims of the present systematic review were (i) to determine the survival rate and (ii) the incidence of complications of multirooted teeth with furcation involvement after a mean observation period of at least 5 years following completion of active periodontal therapy.

Material and Methods

Study selection

Because no randomized-controlled clinical trials (RCCT) have been conducted addressing this topic, this systematic review will focus on subordinate levels of evidence. To be eligible for inclusion in this review, studies had to be longitudinal in nature. Prospective and retrospective cohort studies were considered.

Outcome variables

The primary outcome variable included tooth survival after a mean observation period of at least 5 years. The secondary outcome variables were complications including recurrence of periodontitis, periodontal abscesses, combined endodontic–periodontal lesions, endodontic complications, caries and root fractures.

Literature search

A search in the MEDLINE database up to and including January 2008 was carried out. Only publications in English were considered. In order to be focused, only human trials and dental journals were searched. The search strategy applied was: (periodontal disease[MeSH Terms] AND (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).

A complementary manual search from 1975 up to February 2008 was carried out of the following journals: *The International Journal of Periodontics and Restorative Dentistry*, *Journal of Clinical Periodontology*, *Journal of Periodontal Research* and *Journal of Periodontology*.

In addition, the reference lists of publications selected for inclusion in this review were systematically screened.

Validity assessment

Two reviewers (P. K. and G. E. S.) independently screened the titles, summaries and abstracts of the search results for possible inclusion. The inter-reviewer agreement was calculated by means of κ statistics. The discrepancies were resolved by discussion. Publications of potential interest were searched for in order to evaluate the full text.

The methodological quality assessment and data extraction of the included publications were independently conducted by two reviewers (P. K and G. H.-B.). Any disagreement was resolved by discussion among the two reviewers, including the third reviewer (G. E. S).

Results

Study characteristics

The search resulted in the identification of 888 titles. Independent initial screening of the titles resulted in further consideration of 182 publications. The κ value for inter-reviewer agreement for study inclusion was 0.85, indicating an almost perfect agreement (Landis & Koch 1977). Based on the screening of the abstracts, 52 full-text articles were obtained. From these articles, 19 publications were selected. In addition, three publications were included based on the manual search (Fig. 1).

Out of the initial 888 titles, 836 were excluded based on screening of the titles and abstracts. The reasons for exclusion were:

- Review articles,
- Case reports,
- Observation time <5 years,
- No data on tooth survival and
- No data on furcation involvement.

The full-text articles of the remaining 52 publications were obtained for further evaluation. Thirty-three additional publications were excluded for the following reasons:

- Observation time <5 years: Pontoriero et al. 1989, Garrett et al. 1990, Hürzeler & Strub 1990, Gantes et al. 1991, Newell 1991, Paul et al. 1992, Twohey et al. 1992, Fuentes et al. 1993, Machtei et al. 1993, Mellonig et al. 1994, Basten et al. 1996, Mombelli et al. 1996, Garrett et al. 1997, Rosén et al. 1997, Harris 1998, Anderegg et al. 1999, Karapataki et al. 1999, Dowell & McLaughlin 2000, Ehnevid & Jansson 2001, Hoffmann et al. 2006.
- No data on furcations: Loesche et al. 2002, Tan 2002, Papantonopoulos 2004.
- Unsufficient details regarding the treatment modality of the furcation-involved teeth: Björn & Hjort 1982, Chace & Low 1993, König et al. 2002, Carnevale et al. 2007, Pretzl et al. 2008.
- No data on tooth survival: Ehrlich et al. 1989, Müller et al. 1995, Müller & Eger 1997, Silverstein et al. 1999, Fugazzotto 2001.

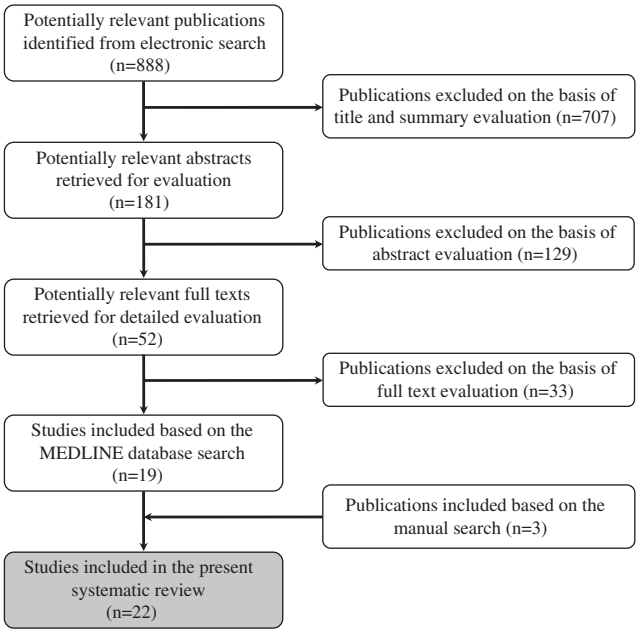

Fig. 1. Selection process of the publications included.

Table 1. Details of the studies included: non-surgical furcation therapy

Study	Hamp et al.	Dannewitz et al.
Year of publication	1975	2006
Study design	Retrospective	Retrospective
Number of subjects	100	71
Age range	Not reported	16–70
Mean age (years)	Not reported	46
Operator	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	62 generalized chronic periodontitis 9 aggressive periodontitis
Treatment	Scaling and root planning	Scaling and root planning
Number of teeth	32	54
Mean observation period	5 years	107 months (62–145 months)
Recall interval	3–6 months	3, 6 months or annual intervals according to the individual risk
Smoking history	Not reported	Active smokers: 43.7% Former smokers: 26.8% Non smokers: 29.5%
Survival rate (%)	100%	90.7%
Frequency distribution of furcation involvements	Not reported	Degree I: 32/54 Degree II: 18/54 Degree III: 4/54

Therefore, from the electronic search of the MEDLINE database, 19 articles were selected. The manual search and screening of the reference list of included publications further included three publications (Bergenholtz 1972, Goldman et al. 1986, Bühler 1988). Thus, a total of 22 publications were included in the present systematic review.

No randomized-controlled trials (RCTs) were identified; therefore, the subordinate levels of evidence, i.e longitudinal cohort studies, mostly retrospective, were included.

Qualitative data synthesis

A preliminary evaluation of the selected publications revealed considerable heterogeneity in terms of the study design, study population, treatment provided, smoking status and recall interval. Hence, it was not appropriate to conduct a quantitative data synthesis leading to a meta-analysis. Thus, it was attempted to report the data by applying descriptive methods. The characteristics of the included 22 publications are summarized in Tables 1–5 according to treatment modalities.

The 22 studies were grouped according to the treatment provided as follows:

Non-surgical furcation therapy (Table 1)

Two clinical trials (Hamp et al. 1975, Dannewitz et al. 2006) examined the survival rate of furcation-involved molars after non-surgical therapy including scaling and root planing and/or furcation odontoplasty. In this context, Hamp et al. (1975) reported a survival rate of 100% at the 5-year examination. It has to be mentioned that these molars had only a Degree I furcation involvement. In the study of Dannewitz et al. (2006), out of 54 non-surgically treated furcation-involved molars, five had to be extracted, corresponding to a survival rate of 90.7% after an observation period ranging from 62 to 145 months (5–12 years). The reason for molar extraction was not reported in the study. Interestingly, out of the five extracted teeth, three teeth had a Degree III, one tooth had a Degree II and one tooth a Degree I furcation involvement at baseline, respectively.

Surgical therapy not involving tooth structures (Table 2)

Ten studies looked at the retention of furcation-involved molars in patients who had been enrolled in the maintenance phase following active periodontal therapy encompassing both non-surgical and surgical therapy. Different types of surgery were performed including but not limited to gingivectomy, gingivoplasty, an apically repositioned flap or a modified Widman flap with or without osseous recontouring.

After a mean observation period of 12 years (range: 5–24 years) after treatment, Ross and Thompson (1978) reported that out of 387 furcation-involved teeth, 341 were still in function, corresponding to a survival rate of 88%.

Hirschfeld and Wasserman (1978) retrospectively analysed a pool of 600 patients followed up for a mean period of 22 years (range: 15–53 years). Out of 1464 teeth with furcation involvement, 460 had to be extracted after active

Table 2. Details of the included studies: surgical therapy not involving tooth structures

Study	Hirschfeld & Wasserman	Ross & Thompson	Mc Fall	Goldman et al.
Year of publication	1978	1978	1982	1986
Number of subjects	600	100	100	211
Study design	Retrospective	Retrospective	Retrospective	Retrospective
Age range	12–73	20–71	8–71	18–67
Mean age (years)	42.2	Not reported	43.8	41.8
Operator	University faculty	Private specialist	University faculty	Private specialist
Periodontal diagnosis	Generalized chronic periodontitis Early: PD $\leqslant$ 4 mm Intermediate: PD 4–7 mm Advanced: PD $\geqslant$ 7 mm Generalized	Generalized chronic periodontitis	Generalized chronic periodontitis Early: PD $\leqslant$ 4 mm Intermediate: PD 4–7 mm Advanced: PD $\geqslant$ 7 mm	Generalized chronic periodontitis Early: PD $\leqslant$ 4 mm Intermediate: PD 4–7 mm Advanced: PD $\geqslant$ 7 mm
Treatment	Scaling and root planing Gingivectomy Osteoplasty Flap surgery	Scaling and root planing Flap procedure without osseous surgery Gingivectomy-gingivoplasty	Scaling and root planing Surgical procedures (gingivectomy, gingivoplasty, ostectomy, mucogingival procedures and flap operations)	Scaling and root planing Surgical procedures (Gingivectomy, gingivoplasty and apical positioned flap) No osseous surgery
Number of teeth	1464	387	163	636
Mean observation period	22 (15–53) years	12 (5–24) years	19 (15–29) years	22 (15–34) years
Recall interval	4–6 months	Not reported	3,4 or 6 months	3–6 months
Smoking history	Not reported	Not reported	Not reported	Not reported
Survival rate (%)	68.8%	88%	43.1%	56.5%
Frequency distribution of furcation involvements	Not reported	Not reported	Not reported	Not reported

Study	Wood et al.	Pearlman et al.	Wang et al.	McLeod et al.
Year of publication	1989	1993	1994	1998
Study design	Retrospective	Retrospective	Retrospective	Retrospective
Number of subjects	63	172	24	114
Age range	24–67	20–73	30–54	26–79
Mean age (years)	45	Not reported	42.9	53
Operator	University faculty	Private specialist	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	Generalized chronic periodontitis Early: PD $\leqslant$ 4 mm Intermediate: PD 4–7 mm Advanced: PD $\geqslant$ 7 mm	Generalized chronic periodontitis	Generalized chronic periodontitis
Treatment	Scaling and root planing Surgical procedures (Gingivectomy, flap surgery, osseous contouring and osseous grafting)	Scaling and root planing Surgical procedures (Flap surgery, including osseous contouring, regeneration with allografts)	Scaling and root planing Surgical procedures (Pocket elimination surgery, MWF or gingival curettage)	Scaling and root planing Surgical procedures (Pocket reduction and elimination, regeneration)
Number of teeth	164	611	80	378
Mean observation period	13.6 (10–34) years	12 (10–15) years	8 years	12.5 (5–29) years
Recall interval	$\leqslant$6, 6–9, $\geqslant$9 months	at least every 6 months	3 months (prophylaxis)	3–6 months
Smoking history	Not reported	Not reported	Not reported	Not reported
Survival rate (%)	76.7%.	73.5%	80%	83.3%.
Frequency distribution of furcation involvements	Not reported	Not reported	Not reported	Not reported

Study	Svärdström & Wennström	Dannewitz et al.
Year of publication	2000	2006
Study design	Retrospective	Retrospective
Number of subjects	160	71
Age range	14–73	16–70
Mean age (years)	44.9	46
Operator	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	

Table 2. (Contd.)

Study	Svärdström & Wennström	Dannewitz et al.
		62 generalized chronic periodontitis 9 aggressive periodontitis
Treatment	Scaling and root planning Surgical procedures (MWF)	Scaling and root planning Flap surgery
Number of teeth	636	140
Mean observation period	9.5 (8–12) years	107 months (62–145 months)
Recall interval	Individual recall interval:	3, 6 months or annual intervals according to the individual risk
Smoking history	Not reported	Active smokers: 43.7% Former smokers: 26.8% Non smokers: 29.5%
Survival rate (%)	96%	93.6%
Frequency distribution of furcation involvements	Not reported	Degree I: 64/140 Degree II: 62/140 Degree III: 14/140

Table 3. Details of the studies included: tunnelling procedure

Study	Hamp et al.	Little et al.	Dannewitz et al.
Year of publication	1975	1995	2006
Study design	Retrospective	Retrospective	Retrospective
Number of subjects	100	18	71
Age range	Not reported	Not reported	16–70
Mean age (years)	Not reported	Not reported	46
Operator	University faculty	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	Generalized chronic periodontitis	62 generalized chronic periodontitis 9 aggressive periodontitis
Treatment	Scaling and root planning Flap surgery and tunnelling	Scaling and root planning Flap surgery and tunnelling	Scaling and root planning Flap surgery and tunnelling
Number of teeth	7	18	14
Mean observation period	5 years	5.8 years	107 months (62–145 months)
Recall interval	Not reported	Every 3 months	3, 6 months or annual intervals According to the individual risk
Smoking history	Not reported	Not reported	Active smokers: 43.7% Former smokers: 26.8% Non smokers: 29.5%
Survival rate (%)	42.9%	88.9%	92.9%
Complications	57.1% caries	16.7% caries	Not reported
Frequency distribution of furcation involvements	Not reported	Not reported	Degree II: 1/14 Degree III: 13/14

periodontal therapy, corresponding to a survival rate of 68.6%.

Following this initial report, many different groups were inspired by the design of the Hirschfeld and Wasserman's study (1978) and reported their outcomes in a similar fashion. Thus, McFall (1982) reported that 43.1% of the molars could be retained after a mean observation period of 19 years (range 15–29 years). The corresponding value for Goldman et al. (1986) was 56.5%, and the mean follow-up period was 22.2 years. Wood et al. (1989) reported a tooth mortality rate of 23.3%, i.e. a survival rate of multirooted teeth of 76.7% over a mean follow-up time of 13.6 years. Pearlman (1993) reported a survival rate of 73.5% after treatment of 611 furcation-involved teeth after a mean follow-up time of 12 years. In this study (Pearlman 1993), the use of bone allografts was one of the furcation treatment modalities. McLeod et al. (1998) reported a survival rate of 83.3% with a follow-up time similar to the previous study (Pearlman 1993).

When looking at the influence of furcation involvement and tooth mobility on changes in clinical attachment levels, Wang et al. (1994) reported that 16 out of the 80 originally furcation-involved molars present at the beginning of the maintenance phase had to be extracted, yielding an 80% survival rate.

Svärdström & Wennström (2000) reported retention of 96% of maxillary and mandibular molars 8–12 years following furcation therapy involving a modified Widman flap procedure.

Dannewitz et al. (2006) treated 140 furcation-involved molars with non-surgical and surgical therapy. After a mean follow-up time of 107 months (approximately 9 years), nine teeth had to be extracted, yielding a survival rate of 93.6%.

Table 4. Details of the studies included: surgical resective therapy (e.g. root resection and/or root separation)

Study	Bergenholtz	Hamp et al.	Langer et al.	Bühler
Year of publication	1972	1975	1981	1988
Study design	Retrospective	Retrospective	Retrospective	Retrospective
Number of subjects	40	100	100	17
Age range	16–63	Not reported	Not reported	20–59
Mean age (years)	Not reported	Not reported	Not reported	50.19
Operator	University faculty	University faculty	Private specialist	Public health service
Periodontal diagnosis	Generalized chronic periodontitis	Generalized chronic periodontitis	Generalized chronic periodontitis	Generalized chronic periodontitis
Treatment	Scaling and root planing Flap surgery and root resection	Scaling and root planing Flap surgery and root resection	Scaling and root planing Flap surgery and root resection	Scaling & root planing Flap surgery and root resection
Number of teeth	45	87	100	28
Mean observation period	5–10 years	5 years	10 years	10 years
Recall interval	Not reported	Not reported	Not reported	6–12 months (Dentist and hygienist)
Smoking history	Not reported	Not reported	Not reported	Not reported
Survival rate (%)	85.0%	100%	62%	67.9%
Complications	66.6% periodontal problems 33.3% root perforation		47.4% root fracture 26.3% periodontal complications 18.4% endodontic failures 7.9% cement washouts leading to caries	33.3% endodontic reasons 22.2% combined periodontal and endodontic reasons 22.2% periodontal reasons 11.1% root fracture 11.1% loss of retention leading to secondary caries
Frequency distribution of furcation involvements	Not reported	Not reported	Not reported	Not reported

Study	Carnevale et al.	Blomlöf et al.	Carnevale et al.	Hou et al
Year of publication	1991	1997	1998	1999
Study design	Retrospective	Retrospective	Prospective	Retrospective
Number of subjects	194	80	72	25
Age range	20–69	34–75	21–62	26–67
Mean age (years)	Not reported	54	42.7	51.4
Operator	Private specialist	University faculty	Private specialist	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	Generalized chronic periodontitis	Generalized chronic periodontitis	Generalized chronic periodontitis
Treatment	Scaling and root planing Apically positioned flap and root resection	Scaling, root planing Flap surgery and root resection	Scaling, root planing Apically positioned flap with osseous contouring and root resection	Scaling and root planing Flap surgery and root resection
Number of teeth	488	78	175	52
Mean observation period	Group 1: 3–6 years including 303 teeth Group 2: 7–11 years including 185 teeth	61–120 months	10 years	6.7 (5–13) years
Recall interval	3 months (95%) 6 months (1%) 1 months (3.5)	3.3 x/Jahr	2–6 months	2–3 months
Smoking history	Not reported	56% smokers	Not reported	Not reported
Survival rate (%)	Group 2: 98.4%	5 years: 83% 10 years: 68%	5 years: 98.9% 10 years: 93.1%	100%
Complications	Group 2: 33.3% caries, 33.3% root fracture 33.3% PPD $\geqslant$ 5 mm	Complications occurring up to 10 years of observation time: 81.3% periodontal disease progression, 25.0% perio-endo lesions 28.1% endodontic lesions	33.3% endodontic complications 25.0% root caries 25.0% periodontal disease recurrence 16.7% root fractures	
Frequency distribution of furcation involvements	No Degree I, only Degree II and III	No Degree I, only Degree II and III	Degree II: 123/175 Degree III: 38/175 N.B: Angular defect 14/175	No Degree I, only Degree II and III

Table 4. (Contd.)

Study	Svärdström & Wennström	Dannewitz et al.
Year of publication	2000	2006
Study design	Retrospective	Retrospective
Number of subjects	160	71
Age range	14–73	16–70
Mean age (years)	44.9	46
Operator	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	62 generalized chronic periodontitis 9 aggressive periodontitis
Treatment	Scaling and root planing Modified Widman flap and root resection	Scaling and root planing Flap surgery and root resection
Number of teeth	47	19
Mean observation period	9.5 (8–12) years	107 months (62–145 months)
Recall interval	Individual recall interval	3, 6 months or annual intervals according to the individual risk
Smoking history	Not reported	Active smokers: 43.7% Former smokers: 26.8% Non smokers: 29.5%
Survival rate (%)	89.4%	57.9%
Complications	80% root fracture	Complication rates following root resection and/or separation not retrievable from reported date
Frequency distribution of furcation involvements	Not reported	Degree I: 3/19 Degree II: 7/19 Degree III: 9/19

Tunnelling (Table 3)

Three publications (Hamp et al. 1975, Little et al. 1995, Dannewitz et al. 2006) looked at the survival rate of furcation-involved molars treated by means of tunnelling.

Hamp et al. (1975) reported that four out of the 7 (57.1%) molars treated with tunnelling developed carious lesions over the 5-year follow-up time. In three out of these four cases, the tooth could not be saved and had to be extracted, yielding an overall survival rate of 57.1%.

Little et al. (1995) reported that three out of 18 (16.7%) multirooted teeth demonstrated caries during a mean follow-up period of 5.8 years, leading to the extraction of two of them. Therefore, a survival rate of 88.9% was reported.

Finally, during the maintenance phase, Dannewitz et al. (2006) had to extract one of the 14 teeth (7.1%) that had undergone tunnelling. The reason for extraction was not reported. The corresponding survival rate was 92.9% after a mean observation period of 107 months.

Surgical resective therapy (e.g. root resection and/or root separation) (Table 4)

Ten studies reported on this specific treatment.

Bergenholtz (1972) reevaluated 45 molars that had been treated with root resections up to 11 years before. Out of 20 resected teeth that were followed up for 5–10 years, 17 teeth were still present. Two teeth were lost because of periodontal complications and one because of root perforation. Hence, the survival rate of resected teeth followed up for 5–10 years reached 85%.

Hamp et al. (1975) reported a survival rate of 100% after 5 years in 87 molars treated by means of root resection and/or separation. Langer et al. (1981) analysed 50 maxillary and 50 mandibular molars resected at least 10 years before reevaluation. They reported a survival rate of 62%, whereby the main causes for tooth loss were root fracture in 18 teeth (47.4%), periodontal complications in 10 teeth (26.3%), endodontic failures in seven teeth (18.4%) and cement washouts leading to caries in three teeth (7.9%). Interestingly, only 15.8% of the tooth loss occurred within the first 5 years after surgery, whereas the vast majority, i.e. 55.3% of the losses occurred between the fifth and the seventh year of function. The remaining losses took place between the eighth and the tenth year of observation.

Bühler (1988) reported the outcomes of 28 root resections performed in 17 patients over a 10-year period. Overall, out of the 28 root-resected teeth, a survival rate of 67.9% was calculated. Similar to the findings of Langer et al. (1981), no tooth loss could be observed during the first 4 years following therapy. However, three resected teeth (10.7%) were lost between the fifth and the seventh year of observation, and six additional teeth were lost between the eighth and the 10th year of observation (21.4%). With decreasing frequencies, the reasons for tooth loss were as follows: endodontic failures 33.3%, combined periodontal and endodontic lesions 22.2%, periodontal reasons 22.2%, root fracture 11.1% and loss of retention leading to secondary caries 11.1%.

Carnevale et al. (1991) reported on the outcomes of 488 teeth treated with hemisection or root amputation. The authors divided the analysis of the teeth into two groups: one with a 3–6-year follow-up including 303 teeth, i.e. 62.4% of the tooth sample and one with a 7–11-year follow-up period. The latter group was included in the present systematic review and corresponded, with 185 teeth, to 37.6% of the tooth sample. Out of these 185 teeth, three teeth were lost, yielding a survival rate of 98.4%. One tooth was lost due to each of the following reasons: caries, root fracture and probing pocket depth >5 mm.

Table 5. Details of the studies included: guided tissue regeneration (GTR) and grafting procedures

Study	Yukna & Yukna	Eickholz & Hausmann	Dannewitz et al.	Eickholz et al.
Year of publication	1997	2002	2006	2006
Study design	Prospective	Prospective	Retrospective	Prospective
Number of subjects	13	19	71	9
Age range	38–64	36–62	16–70	34–58
Mean age	50.9	47.8	46	46.9
Operator	Private specialist	University faculty	University faculty	University faculty
Periodontal diagnosis	Generalized chronic periodontitis	Generalized chronic periodontitis	62 generalized chronic periodontitis 9 aggressive periodontitis	Generalized chronic periodontitis With furcation involvement
Treatment	Scaling and root planing Full-thickness flaps slightly coronally positioned and use of synthetic bone graft	Scaling and root planing Mucoperiosteal flap and GTR using expanded polytetrafluoro-ethylene (ePTFE) and polyglactin 910 membranes	Scaling and root planing Flap surgery and GTR	Scaling and root planing GTR with non-resorbable and resorbable barriers
Number of teeth	16 maxillary molars 10 mandibular molars	20 degree II furcations 10 in the maxilla 10 in the mandible	53 29 Maxillary molars 24 Mandibular molars	18 (9 pairs of contralateral defects) 5 pairs in the maxilla 4 pairs in the mandible
Mean observation period	6.6 (6–7.5) years	60 ± 3 months	107 months (62–145 months)	10 years
Recall interval	3–4 months	3–6 months	3, 6 months or annual intervals according to the individual risk	4–6 months
Smoking history	Not reported	Not reported	Active smokers: 43.7% Former smokers: 26.8% Non smokers: 29.5%	3 patients: smoker $\geqslant$ 10 cigarettes
Survival rate	100%	100%	98.1%	83.3%
Furcation closure	Maxilla 5/16 were clinically closed 6/16 were Degree I 2/16 remained Degree II Mandibula: 3/10 were clinically closed 5/10 were Degree I 2/10 remained Degree II	Not reported	Not reported	0% furcation closure 15/18 defects: Degree II → Degree I 3/18 defects Degree II → Degree III
Frequency distribution of furcation involvements	Degree II: 26/26	Degree II: 20/20	Degree I: 9/53 Degree II: 32/53 Degree III: 12/53	Degree II: 18/18

Blomlöf et al. (1997) analysed 146 teeth that underwent root resections and were followed up for a period up to 10 years. A subgroup of 78 teeth that were followed up for 5 years or more (up to 10 years) could be included in the present study. The survival rate at 5 years was 83.0%, and the corresponding value for the 10-year follow-up was 68.0%. The main reasons for extractions were periodontal disease progression, periodontal–endodontic lesions and endodontic lesions.

Carnevale et al. (1998) evaluated the long-term effect of root-resective therapy in the treatment of furcation-involved molars. This study included 72 patients with a total of 175 molars that underwent root resection and were used as abutments for single unit crowns or fixed dental prostheses. At the 5-year follow-up examination, two teeth were lost because of endodontic complications, corresponding to a survival rate of 98.9%. Within the next 5 years, another nine teeth were lost, resulting in a survival rate of 93.1% at 10 years. The reasons for extraction included endodontic complications (four teeth: 33.3%), root caries (three teeth: 25.0%), periodontal disease recurrence (three teeth: 25.0%) and root fractures (two teeth: 16.7%).

Hou et al. (1999) reported a survival rate of 100% of 52 root-separated molars in a case series comprising 25 patients followed up for a mean observation period of 6.7 years (range 5–13 years).

Svärdström & Wennström (2000) reported a retention rate of 89.4% of 47 molars 8–12 years following root-resective procedures. Five teeth (10.6%) had to be extracted during the follow-up period and root fracture was the main reason for extraction (80.0%)

Dannewitz et al. (2006) performed 19 root resections while treating 305 furcation-involved molars. Eight resected teeth were lost during the maintenance phase, yielding a survival rate of 57.9%.

Guided tissue regeneration (GTR) and grafting procedures-(Table 5)

Four publications (Yukna & Yukna 1997, Eickholz & Hausmann 2002, Dannewitz et al. 2006, Eickholz et al.

2006) were included in this treatment group. Yukna & Yukna (1997) treated 26 Degree II furcation-involved molars by means of bone grafting in conjunction with a coronally advanced flap. Patients were followed up for a period of at least 6 years. All treated molars were still present at the time of reevaluation, yielding a 100% survival rate. Among the treated maxillary molars, the authors were able to close the furcations in five cases, nine improved to Degree I and 2 remained unchanged. The corresponding values for the mandibular molars were 3, 5 and 2, respectively.

Eickholz & Hausmann (2002) treated 18 Degree II furcation-involved molars by applying the principles of GTR. None of the treated molars were lost at the time of reevaluation, i.e. 5 years after surgery.

Dannewitz et al. (2006) treated 53 furcation-involved molars according to the principles of GTR and followed them up during SPT for at least 5 years. One tooth was lost during SPT, yielding a survival rate of 98.1%.

Eickholz et al. (2006) treated 18 Degree II furcation-involved molars and reevaluated them 10 years after therapy. Three molars were lost, corresponding to a survival rate of 83.3%.

Discussion

Considerable heterogeneity was noticeable when comparing the different studies included in the present systematic review. This precluded the performance of a meta-analysis. Progress and evolution in disease diagnosis and a better understanding of the pathogenesis of periodontal disease have led to modifications in treatment planning. The treatment of furcation-involved teeth, however, still represents a challenge for clinicians. When analysing data available in the literature over a 30-year period, a wide variety of treatment options were advocated including recent surgical approaches such as tissue-regenerative procedures (Jepsen et al. 2002, 2004). Therefore, it seemed inappropriate to compare these recent results (Jepsen et al. 2002, 2004) with outcomes from studies published in the 1970s (Bergenholtz 1972, Hamp et al. 1975).

No study with comparison of treatment outcomes (i.e. RCCT) between different procedures was identified. This in turn limits the applicability of the results for periodontal practice. Because no treatment was clearly and adequately shown to be superior to another in terms of tooth survival, treatment decisions and guidelines could not be recommended based on the present systematic review.

Furthermore, because most of the included studies, i.e. 18 out of 22 (82%), were retrospective in nature, the risk of bias could not be excluded and quality criteria including allocation concealment, blinding of outcome assessor or completeness of follow-up could not be determined. Out of the descriptive analysis performed in the present systematic review, several comments are warranted according to the treatment performed. Non-surgical conservative furcation therapy is effective in preventing Degree I furcation-involved teeth from further interradicular disease progression. As the lesion progresses, leading to greater attachment loss, this treatment presents some limitations including incomplete removal of calculus (Matia et al. 1986, Fleischer et al. 1989, Parashis et al. 1993a, b, Wylam et al. 1993). Moreover, severe furcation involvement (i.e. Degree II and III) cannot be optimally cleaned by the patient without changing the interradicular anatomy. Therefore, severe furcation involvement is only suboptimally treated with non-surgical therapy and inadequately maintained by the patient's home care, eventually leading to tooth loss (Dannewitz et al. 2006, Carnevale et al. 2007).

Various surgical approaches (i.e. gingivectomy, flap curettage, a modified Widman flap, an apically repositioned flap with or without osseous recontouring) have been designed with the common aim of completely removing all supra- and sub-gingival bacterial deposits. The survival rates of furcation-involved teeth following surgical procedures ranged from 43.1% to 96% after a mean observation period ranging from 8 to 22 years.

Less favourable outcomes with respect to tooth survival after active periodontal therapy have been associated with the initial severity of furcation involvement (McGuire & Nunn 1996, Cattabriga et al. 2000, Pretzl et al. 2008). Moreover, furcation sites associated with a longer recall interval period during SPT (i.e. 18 months) showed a tendency towards a higher frequency of attachment loss of $\geqslant 1$ mm when compared with that of other groups on a shorter recall interval (Rosén et al. 1999).

In addition to poor plaque control, cigarette smoking has not only been recognized as a major risk factor for periodontal disease progression (Beck et al. 1990, Bergström & Preber 1994, Tomar & Asma 2000, Heitz-Mayfield 2005), but has also been associated with increased prevalence of furcation-involved teeth (Mullally & Linden 1996).

Eventually, individual susceptibility to periodontal disease may be influenced by genetic factors (Michalowicz et al. 1991, 2000, Michalowicz 1994). However, whether or not genetic susceptibility to periodontal disease may also play a role in the survival of multirooted teeth with furcation involvement remains to be established.

Therefore, explanations for the discrepancies among the studies in terms of the survival rate of surgically treated furcation-involved molars may include differences in the severity of furcation involvement at baseline, duration of recall intervals, levels of plaque control and presence of risk factors such as smoking and genetic susceptibility.

A tunnelling procedure may be considered a valid alternative to render an advanced Degree II or III furcation-involved molar cleansable for the patient and overcome the less favourable prognosis if left untreated. This procedure is best performed when the tooth presents a short root trunk and a favourable root divergence. Furthermore, the avoidance of endodontic treatment and fabrication of a crown makes this treatment a valid conservative and cost-effective alternative to retain molars with severe intrafurcal attachment loss. The survival rate associated with this procedure ranges from 57.1% to 92.9% after an observation period of at least 5 years. However, increased root surface exposure is associated with higher caries incidence. Therefore, topical application of fluoride or chlorhexidine varnishes is mandatory to overcome caries development in the furcation area (for a review, see Zimmer et al. 2003).

Evidence for tooth survival following tunnelling is based on clinical studies with a limited number of cases (i.e. seven to 18 teeth per study), and caution should be exercised when interpreting the outcome of this procedure.

Root-resective procedures are further alternatives to treat furcation-involved molars. The survival rates reported in the studies included in the present sys-

tematic review ranged from 57.9% to 100% after a mean observation period of 5–10 years. The reasons for tooth extraction were mainly related to endodontic complications and root fractures and not to periodontal disease recurrence.

While two studies (Langer et al. 1981, Bühler 1988) reported a survival rate of around 65% after a mean observation period of 10 years, other studies reported survival rates close to or above 90% (Carnevale et al. 1991, Svärdström & Wennström 2000) over a similar observation period. Such differences may, in part, be attributed to the pre-therapeutic situation of furcation-involved molars. In other words, some may have retained more questionable teeth that would have led to less favourable overall survival rates, whereas others would have extracted them during initial periodontal therapy. In addition to periodontal reasons, untreatable caries and endodontic complications could not be excluded in most of the included publications as important causes for molar tooth extraction. Many studies reported failures occurring after an observation period of 5 years (Langer et al. 1981, Blomlöf et al. 1997, Carnevale et al. 1998). Therefore, it seemed justified to evaluate the outcomes of furcation therapy after an observation period of at least 5 years.

Using the principles of GTR, different authors reported survival rates ranging from 83.3% to 100% in the treatment of furcation-involved molars. The severity of the initial furcation lesions was shown to influence the outcome of GTR in such areas (Jepsen et al. 2002, 2004, Bowers et al. 2003, Horwitz et al. 2004). Outcomes from short-term studies, with re-entry at 6 months after treatment, have shown that furcation closure of Degree II defects could be attained, but it was not a consistent finding. An improvement of the horizontal probing depth could generally be observed for Degree II mandibular molars. Treatment of maxillary Degree II furcations with GTR revealed little or no improvement. Indeed, the addition of GTR to open flap debridement resulted in probing attachment and bone gain in buccal furcations of maxillary molars, while this was not the case for the corresponding interproximal furcations (Pontoriero & Lindhe 1995). To date, Degree III cannot predictably be closed by means of GTR (for a review, see Sanz & Giovannoli 2000).

A treatment alternative to GTR in the attempt to close furcation-involved molars includes the use of enamel matrix derivatives (EMDs). To date, only a few short-term reports are available on this regenerative procedure (Donos et al. 2003, 2004, Jepsen et al. 2004, Casarin et al. 2008). These have demonstrated that horizontal furcation depth reduction was achieved in most of the cases but complete furcation closure was not a consistent finding. Further research is needed in this field to ascertain the long-term stability of these encouraging treatment outcomes.

Comparative evidence of the long-term treatment outcomes of furcation-involved teeth with implant placement in molar position is scarce. A study by Fugazzotto (2001) reported the success rates of root-resected molars and implants placed in the molar region for a period of up to 15 years in a private practice setting. The success criteria for resected teeth were defined as absence of probing depth >4 mm, absence of bleeding on probing at more than one maintenance visit, absence of exudation and absence of recurrent caries or root fractures. The success criteria defined by *Albrektsson et al. (1986)* were used to assess the outcomes of implant therapy. When comparing the two groups including 701 resected molars and 1472 implants, the success rates reached 96.8% and 97.0%, respectively. Hence, even in cases of furcation-involved molars, it was worth maintaining the tooth with a resective procedure, which displayed a success rate comparable with that of implant placement. In addition, maintenance of a furcation-involved molar in an inflammation-free environment would not preclude implant placement in the future.

Based on the outcomes of the present systematic review, it can be concluded that good long-term survival rates of multirooted teeth with furcation involvement were found following various therapeutic approaches.

Initial furcation involvement (Degree I) could be successfully managed by non-surgical mechanical debridement.

Caries development in the furcation area was the most frequent reason for molar extraction after a tunnelling procedure.

The most frequent complications following resective procedures were not associated with progression of periodontal disease, but were related to vertical root fractures and endodontic failures.

Complete furcation closure was not predictably achieved following GTR or the application of EMD in maxillary and mandibular molars.

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Clinical Relevance

Scientific rationale for the study: Treatment of furcation-involved teeth represents a clinical challenge and many therapeutic modalities have been advocated.

Principal findings: Good long-term survival rates (up to 100%) were found following therapy of furcation-involved multirooted teeth. Endodontic failures, root fractures and caries development in the furcation area represented the most frequent complications leading to tooth loss. No RCTs were available comparing the long-term (5 years or more) outcomes of different treatment modalities of molars with comparable degree of furcation involvement.

Practical implications: A wide variety of treatment modalities can successfully be applied to treat furcation-involved multirooted teeth. However, limitations of the available evidence do not allow any conclusive remarks as whether one procedure should be chosen over another in order to improve survival rates.