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ORIGINAL ARTICLE

Retention of molars after root-resective therapy: a retrospective evaluation of up to 30 years

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Abstract
Objectives Long-term retention of teeth and especially molars in function is the ultimate goal of periodontal therapy. Root-resective therapy is a treatment option for molars with advanced furcation involvement, which has been questioned because of the heterogenous success rates published in literature. This study aimed to evaluate long-term results of root-resective treatment over a period of up to 30 years.
Methods In this retrospective cohort, 90 root-resected molars in 69 patients were examined for 4–30 years (14.7 ± 6.8 years). The complete treatment sequence was performed by one of the authors in a general dental practice.
Results Overall cumulative survival rate was 90.6% after 10 years, but then decreased considerably. Molars after root resection had a median survival time of 20 years. The incidence of endodontic complications leading to tooth extraction was only 26.7%, 50% were lost due to periodontal problems, and 16.7% because of caries. Mandibular molars had a significantly lower relative risk of loss than molars in the maxilla (HR 0.31, 95% CI 0.1–0.91, $p = 0.033$). Mandibular molars showed a survival probability of almost 80% even 20 years after root resection.
Conclusion Root-resective therapy is a predictable treatment option, when care is administered at each phase of therapy.
Clinical relevance This study provides important information about what is possible in daily practice under the outlines of public health care, when care is administered at each phase of resective therapy.

Keywords Resective therapy · Tooth loss · Tooth survival · Tooth retention · Molar · Long-term results

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Introduction

The destruction of bone and connective tissue due to periodontal infection can progress into the furcation area of multi-rooted teeth. The morphology of the inter-radicular space provides a favorable environment for plaque accumulation and impedes accessibility for individual oral hygiene care and professional root instrumentation. Therefore, advanced furcation involvement (FI) is one of the most relevant factors that reduces the long-term prognosis of multi-rooted teeth [1–5]. Root-resective procedures are treatment options for the management of furcation-involved teeth and aim to eliminate this plaque-retentive niche and to establish a morphology that facilitates proper self-performed plaque control. Several studies have outlined the technique and listed the indications and contraindications [6, 7]. Resective procedures can be classified into root separation (RS) with sectioning of the root complex and maintenance of all roots or root separation and resection (RSR), which also includes the removal of a root with or without the associated part of the crown [6]. A long-term successful outcome of root-resective procedures depends not only on careful periodontal therapy but also on meticulous

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endodontic and restorative treatment and a highly motivated patient [8].

The survival data of teeth after resective treatment varies greatly [9]. Several authors have shown excellent retention of resected molars for periods averaging 3–5 years. However, longitudinal studies of 10 years have yielded mixed results. The high degree of complexity and various treatment settings may contribute to the significant variability in reported clinical outcomes. In light of the heterogeneous survival data and the rise in the popularity of dental implants, root-resective therapy has lost acceptance among many clinicians.

The aim of the present study was to evaluate the long-term results of root-resective treatment performed in a general practice and followed up on a regular basis for up to 30 years.

Materials and methods

This study presents a 30-year retrospective evaluation of 90 molars from 69 patients who underwent root-resective treatment in a private practice. The investigation consecutively covers all cases from 1983 to 2009 in which this type of surgery had been utilized and the patient subsequently returned regularly or periodically for dental check-ups and/or treatment in this practice. The complete treatment sequence, including endodontic therapy, root resection, and prosthetic reconstruction, were solely performed by one of the authors (HD). The need for RS/RSR was determined by a variety of factors: periodontal, endodontic, and/or caries. Therefore, not all patients underwent systematic periodontal therapy before resective therapy. After the endodontic, resective, and prosthetic treatment was completed, patients were enrolled individually in a personalized maintenance program or supportive periodontal care, including at least annual examinations of the oral and periodontal situation and regular periodic professional mechanical plaque removal combined with re-instruction and re-motivation for effective plaque control, usually in half-yearly intervals. This study was approved by the Institutional Review Board for Human Studies of the Medical Faculty of Goethe-University Frankfurt (Application 71/17).

Endodontic, surgical, and restorative treatment protocol

Endodontic treatment was always completed before the surgical phase. From 1983 until 1996, root canals were prepared with conventional hand instrumentation techniques, which were then superseded by automated root canal preparation under high magnification. The access opening was kept as small as possible, and excessive preparation of the root canals was avoided to maintain as much intact dental hard tissue structure as possible. Subsequently, root canals were filled with a cold lateral compaction of gutta-percha combined with sealer. To provide internal support and retention for the prosthodontic reconstruction, the teeth were built up with non-adhesive or adhesive core-filling materials and, if necessary, the use of an additional post.

In a few cases (advanced gingival recession, class III furcation with a supra-gingival furcation entrance), RSR was performed completely without raising a flap. Otherwise, a mucoperiosteal flap was elevated, usually after cutting the root with a high-speed burr to prevent metallic fragments and tooth particles from becoming embedded in the soft tissue. Then, the resected portion of the tooth was extracted, followed by a thorough debridement of the remaining root surfaces and proper contouring of the remaining tooth structure to eliminate any residual undercuts and to minimize plaque retention. Further osteotomy or osteoplasty was performed if needed. Suturing and the post-surgical protocol were driven by the individual situation and were performed according to standard periodontal surgical procedures.

Additional elements of the surgical phase included the preliminary prosthetic preparation of the remaining roots/teeth and the insertion of a pre-fabricated temporary restoration. After the healing phase, final tooth preparation and reconstruction were performed either as a single crown, a bridge abutment or as double-crown abutments for removable dentures. Occlusion of the tooth was thoroughly evaluated and adjusted to prevent excessive forces.

Evaluation of the endodontic/periapical status

Radiographs (periapical and/or panoramic) were taken routinely at the following intervals: before resective therapy, after root resection, after completion of prosthetic rehabilitation, and at the last dental check-up (Fig. 1).

The periapical status was assessed on the last available radiograph by a calibrated endodontist (TP) with the Periapical Index (PAI): (1) normal periapical structure, (2) small changes in bone structure, (3) changes in bone structure with some mineral loss, (4) periodontitis with a well-defined radiolucent area, and (5) severe periodontitis with exacerbating features [10]. In the case of different periapical conditions within one tooth, the molar was characterized by the worst PAI score. Length of obturated root canals was classified into two groups: (1) 0–2 mm within the radiographic apex and (2) obturated past or more than 2-mm short to the radiographic apex [11].

Assessment of the periodontal situation at the last dental visit

At the last examination, the periodontal situation was evaluated at the remaining molars (HD). Probing pocket depth (PPD) was measured at the mesial, distal, buccal, and

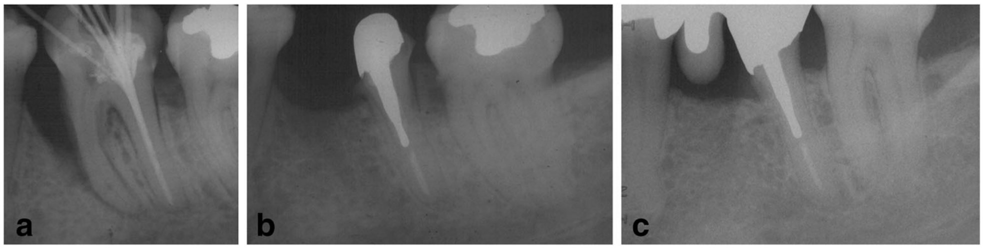

Fig. 1 Example for the treatment sequence. Tooth 36 with deep infrabony defect at the mesial aspect and furcation involvement due to periodontitis, root canal treatment of the distal root (**a**, 27.01.1983). Radiographic control after resection of the mesial root and insertion of a post (**b**, 27.01.1983). Radiographic follow-up of the tooth, which was used as bridge abutment and is still in function 30 years after resective therapy (**c**, 22.02.2013)

lingual/oral aspect of the tooth with a calibrated probe (PCP-UNC 15). Tooth mobility was graded as follows: (1) no apparent mobility, (2) mobility just palpable, (3) mobility visible, and (4) mobility on lip or tongue pressure and/or in an axial direction [12].

Statistical analysis

Data were extracted from the patients' records, entered into a computer database, and corrected for implausible entries (DW). Descriptive analyses and the calculation of cumulative survival probabilities were performed with SPSS version 24.0 (SPSS Inc., Chicago, IL, USA; BD and PE). Tooth loss during follow-up was defined as a main outcome variable. Survival curves were calculated via the non-parametric Kaplan-Meier method. The overall differences between estimated survival curves of molars by tooth location (upper vs. lower jaw), the number of resected roots, the type of resective procedure (RS vs. RSR), and prosthetic rehabilitation were compared via log-rank test. A Cox proportional hazard model was used for multivariate analysis to identify independent factors that affected survival based on variables selected by univariate analysis and to obtain adjusted hazard ratios. Multilevel analysis was performed with R 3.1.1. (R Foundation for Statistical Computing, Vienna, Austria). Specifically, the coxph () function from the survival package, version 2.12-2 (http://cran.r-project.org/web/Packages/survival/index.html), was used for the analysis. To identify prognostic factors for the survival of molars after root resection, a proportional hazard model for time-to-event data was applied, and a patient-specific gamma distribution was used for shared frailty. The consideration of a patient-specific risk is important, so as not to neglect the dependency between different molars of the same patient, resulting in biased estimates for the hazard ratios [13]. The shared frailty term is used to model this dependency. A p value of less than 0.05 indicated a significant difference.

Results

Patient and tooth characteristics

The demographic and tooth-related characteristics at the time of resective therapy are summarized in Table 1. A total of 69 patients (43.5% female) with a median age of 54 years (23 to 89 years) were examined. The mean observation period was 14.7 ± 6.8 years (4.2 to 30 years), and 51 patients (73.9%) were followed for more than 10 years. A total of 90 molars were subjected to root-resective therapy; 29 (32.2%) were upper and 61 (67.8%) were lower molars. Third molars (3.3%) were considerably less common than second (33.3%) and first (63.3%) molars (Fig. 1). Fifteen patients had more than 1 molar with root resection: 10 patients had 2 molars, 4 patients had 3 molars and 1 patient had 4 molars (Table 1).

Only five teeth (5.6%) received RS with complex sectioning of the root but without removal of a root, and all were lower first molars. The majority (94.4%) of molars were treated with RSR. In 69 cases (81.2%), only one root was removed and in 16 teeth (18.8%) two roots were resected. The distribution of resected roots is given in Table 2. In the lower jaw, distal roots were most often retained (64.3%), whereas in the maxilla, the preservation of the palatal root was most common (65.5%).

In 81 cases, the indication for root-resective therapy had been recorded in the patients' charts. Periodontal problems were the most frequent reason (61.7%) for treatment, followed by caries (18.6%), endodontic indications (13.6%), and other causes (6.2%).

Fifty-one resected molars were used as bridge abutment (56.7%), 33 teeth were rehabilitated with single crowns (36.7%), and six molars (6.7%) were used as double-crown abutments for removable dentures (Table 2).

Endodontic status

Radiographically, 35 molars (38.9%) demonstrated a root canal filling within 2 mm to the radiographic apex; in 45 molars (50%) the fillings were too short (> 2 mm)

Table 1 Demographic and tooth-related characteristics of the subject sample at beginning of resective therapy

Number of subjects	69
Females/males (%)	30 (43.5)/39 (56.5)
Median age/range (years)	54/23–89
Mean follow-up ± SD (years)	14.7 ± 6.8
Range of follow-up (years)	4.2–30
Number of molars with resective therapy	90
Patients with 1 molar (%)	54 (78.3)
Patients with 2 molar (%)	10 (14.5)
Patients with 3 molar (%)	4 (5.8%)
Patients with 4 molar (%)	1 (1.4%)
Upper jaw/lower jaw (%)	29 (32.2)/61 (67.8)

SD, standard deviation

or beyond the apex, and 10 teeth (11.1%) could not be evaluated adequately. The periapical status was rated as follows: 20.0% PAI score 1, 24.4% score 2, 35.6% score 3, 11.1% score 4, 4.4% score 5, and 4 molars (4.4%) could not be assessed sufficiently. In 39 molars (43.3%), a post was placed. There was no significant association between either the length of the root canal filling or the presence of a post and PAI score or tooth loss (dependencies were tested applying the chi-square test and PAI was categorized as score 1/2 [n = 40] vs. 3/4/5 [n = 46]).

Periodontal situation of remaining molars

Sixty molars were still present at the last recall visit, and the periodontal situation was recorded in 58 of these molars. The mean PPD was 3.02 ± 0.96 mm; 68.9% of sites had a PPD of 4 mm or less, 25.8% of sites had a PPD of 5 and 6 mm, and 5.5% of sites had a PPD of 7 mm and more (the deepest record was 9 mm). There were no significant differences in the mean PPD for molars restored with single crowns, bridge abutments, or double crowns (3.1, 3.0, and 2.9 mm, respectively) or for upper and lower molars (3.3 and 2.9 mm, respectively).

Tooth mobility could be assessed in all remaining molars and was graded as follows: 33 teeth without apparent mobility (55.0%), 23 molars in which the mobility was just palpable (38.3%), 3 molars with visible mobility (5.0%), and 1 tooth with mobility on lip or tongue pressure and/or in an axial direction (1.7%). However, the mobility of root-resected molars is difficult to judge because the majority of teeth were used as abutments for bridges.

Retention of root-resected molars

A total of 30 molars (33.3%) were extracted during the follow-up in 24 (34.8%) of the 69 patients included in this study (Fig. 2). Eighteen patients lost only one molar, and six patients lost two molars each. Forty percent of the extracted molars were therefore lost in only 8.7% of the patients.

Upper molars accounted for the loss of 11 teeth (37.9%), and 19 mandibular molars (31.1%) were extracted. Twenty of

Table 2 Distribution of resected roots, prosthetic rehabilitation and failures

Jaw	Tooth type	Resected root	*n*	Crown	Bridge	Double-crown	Failed
Upper jaw (n = 29)	First molar (n = 22)	m	1	1			
		d	4	3	1		
		p	5	3/*3*	2/*1*		*4*
		m + d	11	6	3/*1*	2/*2*	*3*
		d + p	1		1/*1*		*1*
	Second molar (n = 7)	m	1			1/*1*	*1*
		d	1	1			
		p	1	1			
		m + d	1	1/*1*			*1*
		d + p	3	1/*1*	2		*1*
Lower jaw (n = 61)	First molar (n = 30)	m	21	4/*1*	17/*4*		*5*
		d	9	3/*2*	5/*3*	1	*5*
	Second molar (n = 23)	m	12		11/*5*	1	*5*
		d	11	4	7/*1*		*1*
	Third molar (n = 3)	m	3		2	1/*1*	*1*
	First molar (n = 5)	RS	5	5/*2*			*2*
Total			90	33/*10*	51/*16*	6/*4*	*30*

d, distal; *m*, mesial, *p*, palatal; *RS*, root separation

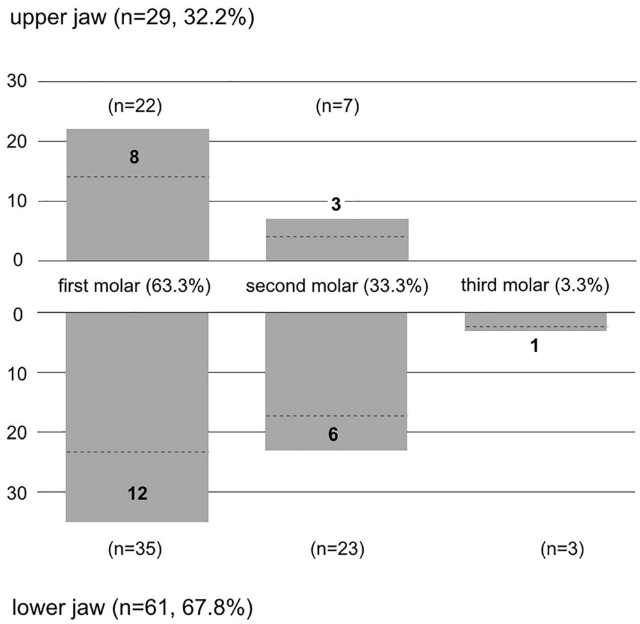

Fig. 2 Distribution of 90 molars at the time of root-resective therapy. Twenty-nine (32.2%) were maxillary and 61 (67.8%) were mandibular molars. The main tooth type was first (63.3%) followed by second (33.3%) and third (3.3%) molars. A total of 30 teeth failed during follow-up. Maxillary molars accounted for the loss of 11 teeth (37.9%), while 19 mandibular molars (31.1%) were extracted. Twenty of the first (35.1%), 30% of the second, and 33.3% of the third molars were extracted. (Numbers are shown in bold, and the proportions of extracted teeth within the columns are accentuated by dotted lines)

the first (35.1%), 30% of the second, and 33.3% of the third molars were lost (Fig. 2). Two of the molars after RS (40%) and 28 teeth after RSR (32.9%) were lost. Four molars that were used as double-crown abutments were lost (66.7%), but only 30.3 and 31.4% of teeth that had been restored as crowns or fixed-bridge abutments, respectively (Table 1).

The indication for extraction was documented in all molars. Half (50%) of the extracted molars were lost due to periodontal problems, followed by endodontic complications (26.7%), caries (16.7%), and other reasons in 2 cases. All molars that were extracted due to endodontic problems had a PAI score of 3, 4, or 5.

The first molar lost in this study sample was extracted 52 months after root-resective therapy (Fig. 3). Seven extractions occurred within the first 10 years, which resulted in a cumulative survival rate of 90.6% (upper jaw 80% and lower jaw 94.6%). Survival probability decreased considerably after 10 years, and was 68.9% after 15 years, 43.6% after 20 years, and 34.9% after 25 to 30 years. The mean survival time of resected molars was 245 months (95% CI 217–274 months). The median age of patients at the time of extraction was 64 years (44 to 93 years). With regard to the survival probability, upper molars showed a significantly shorter median survival rate than lower molars (176 vs. 289 months, p = 0.011), as did teeth that were rehabilitated as double-crown abutments compared with bridge abutments and single crowns (150, 289, and 211 months, respectively, p = 0.033).

The multivariate regression model accounting for jaw, PAI score, number of resected roots, and prosthetic rehabilitation revealed only location as a factor that significantly affected the loss of molars after resective therapy. Mandibular molars had a significantly lower relative risk for loss than molars in the maxilla (HR 0.31, 95% CI 0.1–0.91, p = 0.033).

Discussion

The prognosis of root resection is well documented in the literature, but remarkable heterogeneity is noticeable when comparing different studies (Table 3). In the present study, 30 of 90 molars (33.3%) were extracted during a mean follow-up period of 14.7 years. However, the serial time of included patients varies considerably (4–30 years) and in many subjects, the observation ended without tooth loss. Therefore, we calculated not the absolute survival rate, but the cumulative survival probability. Cumulative survival probability decreased from 98.9% after 5 years to 90.6% after 10 years, 68.9% after 15 years, 43.6% after 20 years, and 34.9% after 25 to 30 years. Lower molars showed a survival probability of almost 80% even 20 years after root resection. To our knowledge, this is the first study to report the survival of resected molars over a period of up to 30 years, and approximately 74% of included patients were followed for more than 10 years.

The published inconsistent retention rates are often considered unacceptable for the complex and costly root-resective therapy of molars. However, most of the extractions reported for teeth after root resection in different studies are caused by reasons other than periodontal disease recurrence [6, 17–19, 23]. The main reasons for extraction are endodontic-related complications, caries, and restorative problems. Many factors have been associated with the long-term success of endodontic therapy, including the use of rubber dams, the use of surgical operating microscopes, the quality of post-endodontic restoration, and provider training [26–29]. Some of these aspects have very recently become routine dental practice and have not been applied in most of the studies on root-resective therapy. Molars pose a particular challenge for periodontal and endodontic treatment due to their specific anatomy. An evaluation of the outcome of primary endodontic therapy in molars via an insurance company database revealed that molars treated by trained endodontists had a significantly higher survival rate after 10 years compared with those molars treated by general dentists (89 vs. 84%, respectively) [30]. This result emphasizes the full use of modern, accepted techniques for endodontic treatment during the course of the resective procedure to improve the long-term prognosis of these teeth. In the present study, the complete treatment sequence was performed

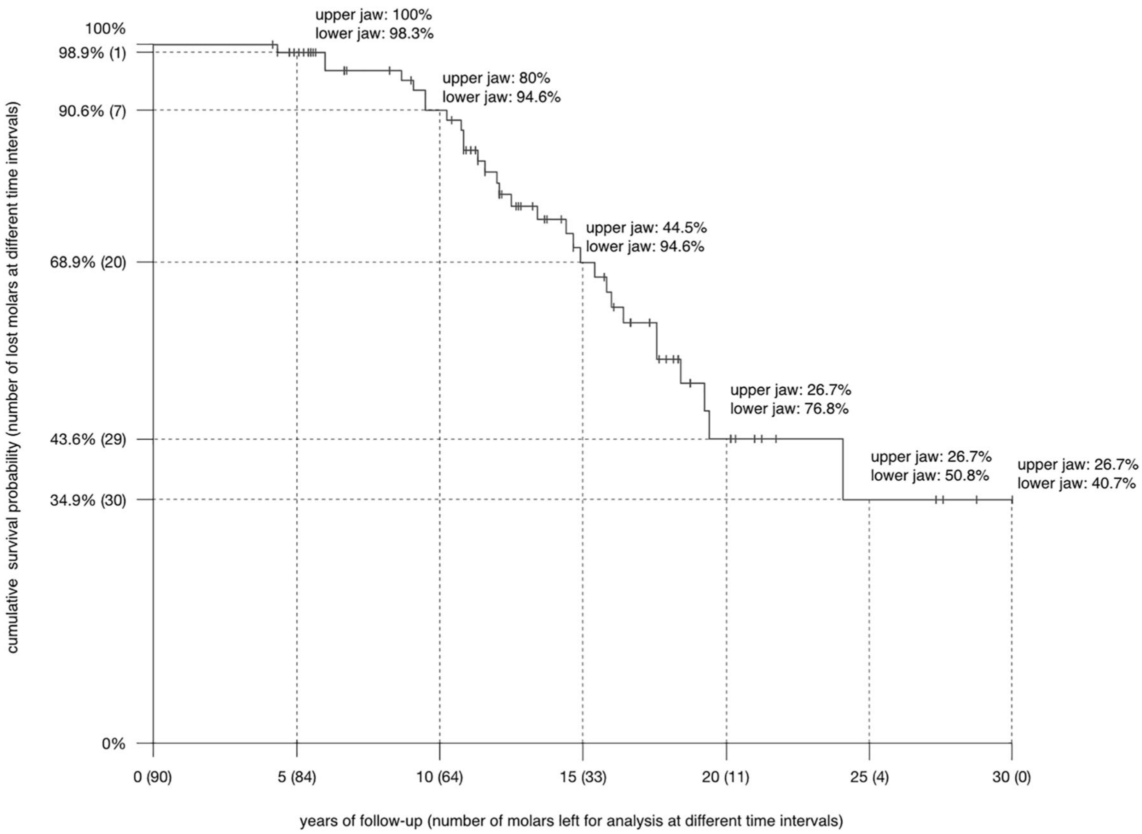

Fig. 3 Kaplan-Meier survival plot for molars after root-resective therapy. Censored subjects are indicated on the curve as tick marks. The first molar was extracted 52 months after therapy. Cumulative survival probability decreased from 98.9% after 5 years to 90.6% after 10 years, 68.9% after 15 years, 43.6% after 20 years, and 34.9% after 25 to 30 years. Lower molars showed a survival probability of almost 80% even 20 years after root resection. The mean survival time of resected molars was 245 months (95% CI 217–274 months)

by only one person in a private practice setting. However, this dentist was highly skilled and experienced not only in periodontology and reconstructive dentistry but also in endodontology. Thus, the incidence of endodontic complications leading to the extraction of a molar was only 26.7% and remarkably low compared with that of other studies describing tooth loss rates due to endodontic origin of up to 85.7% [18]. Langer et al. identified fractures as the most common reason for tooth loss in their study [17]. Excessive loss of natural tooth substance during endodontic treatment, the use of posts or core, and parafunctional habits along with the reduced size of the remaining root complex may increase the susceptibility of resected molars to root fractures. Even though a post was placed in almost half of the molars (43%), great care was taken to preserve as much tooth structure as possible during the endodontic treatment. Furthermore, in all cases, the occlusal scheme was carefully adjusted to minimize excessive loads. Both factors might be crucial and might explain why no root fractures occurred during the follow-up in the present study.

The univariate analysis revealed that several tooth-specific factors significantly deteriorated the survival time of molars, including tooth location and prosthetic rehabilitation. However, in the multivariate regression model, only tooth location had a significant impact on the retention of resected molars. In the present study, upper molars were lost more frequently than lower molars. Our analysis did not identify any substantial difference in the indications for tooth extraction of upper and lower molars, but almost all maxillary molars were lost after the resection of the palatal root.

Especially in maxillary molars, three-dimensional findings from cone beam computed tomography (CBCT) may add substantial information about the furcation/root morphology and degree of FI [31]. Compared to conventional radiography, CBCT implies considerably higher radiation doses and costs for the patient. However, molars with high strategic value may benefit from more detailed, radiographic information as basis for complex treatment decisions [32]. However, three-dimensional imaging was not utilized in any of the included patients, since this technology was not available in the dental office at this time.

Maxillary molars with advanced FI often have a substantial reduced inter-furcal bone height [32]. Following the extraction of a periodontally compromised maxillary molar, the amount of remaining bone is further reduced due to vertical ridge resorption. Subsequent implant placement may then require sinus floor elevation, other

Table 3 Synopsis of studies reporting about survival rates of teeth after root-resective therapy

	Number of subjects	Number of teeth (treatment period)	Observation period	Absolute failure rates (%)	Reasons for failure
Bergenholz 1972 [14]	40	45	Up to10 years	6% (3)	66.7% endo/paro 33.3% endo
Klavan 1975 [15]	29	34	11–84 months	3% (1)	Not reported
Hamp et al. 1975 [16]	100	87	5 years	0% (0)	
Langer et al. 1981 [17]	100	100	10 years	6% (6) after 4 years 27% (27) after 7 years 38% (38) after 10 years	26.3% perio 47.4% fracture 18.4% endo 7.9% cement washout/caries
Erpenstein 1983 [18]	28	34 (1974–1981)	1–7 years	20.6% (7)	14.3% perio 85.7% endo
Bühler 1988 [19]	17	28	10 years	0% (0) after 4 years 10.7% (3) after 5–7 years 32.1% (9) after 8–10 years	(3) 22.2% perio 11.1% fracture 33.4% endo 22.2% endo/paro 11.1% loss of retention
Carnevale et al. 1991 [20]	194	488	3–6 years (303 teeth) 7–11 years (185 teeth)*	4.9% (15) after 3–6 years 1.6% (3) after 7–11 years	6.6/33.3%* perio 46.7/33.3%* fracture 26.7% endo 20/33.3%* caries
Basten et al. 1996 [21]	32	49 (1972–1993)	2–23 years	8.2% (4)	25% endo 50% caries 25% strategic
Blomlöf et al. 1997 [22]	80	146 (1981–1988)	10 years	17% (25) after 5 years 21.9% (32) after 10 years	28.1% perio 53.1% paro-endo 6.3% fracture
Carnevale et al. 1998 [23]	72	175	10 years	7% (12)	25% perio 16.7% fracture 33.3% endo 25% caries
Hou et al. 1999 [24]	25	52 (1980–1997)	5–13 years	0% (0)	
Svardström and Wennström 2000 [25]	160	47 (1978–1984)	8–12 years	11% (5)	80% fracture
Dannewitz et al. 2006 [24]	71	20 (1992–1995)	62–107 months	40% (8)	Not reported
Dannewitz et al. 2016 [2]	136	44 (1990–2002)	10–20 years	38.6% (17)	Not reported

augmentative procedures, or alternatively, the use of short implants.

Dental implants have increasingly replaced resective therapy as an approach for maintaining molars with advanced FI in clinical practice. The 5-year survival rate of single crown implants and implant-supported fixed dental prostheses (FDPs) is estimated to be between 97.7 and 93.6%, and the 10-year survival rate is estimated to be between 94.9 and 86.7% [33]. Survival rates of implants in the posterior maxilla might be less favorable [34]. Furthermore, implants placed in patients who were treated for periodontal disease are associated with a higher incidence of biological complications and lower success and survival rates than those placed in periodontally healthy patients [35]. In the present study, the overall cumulative survival of resected molars after 10 years was 90.6%, and more than 50% of the teeth were used as bridge abutments. Thus, the survival of implants and root-resected molars over a period of 10 years is not significantly different, as demonstrated by others. Fugazzotto et al. reported a 15-year cumulative success rate of 96.8% for root-resected molars and 97% for molar implants [36]. In contrast to our study, definition of success was not focused on tooth retention alone but included strict clinical criteria including among others no PPD greater than 4 mm [36]. In about 30% of the remaining 60 molars in this study, PPD was greater than 4 mm and therefore according to the criteria applied by Fugazotto et al. not successful even if they are still in function.

Maintaining a molar in an inflammation-free environment will prevent further bone loss compromising any potential future implant placement. This result is an important argument for choosing resective procedures, especially in younger patients (e.g., patients with aggressive periodontitis), thus postponing the time for potential implant placement in a later phase of life.

This study has several limitations because the data are the results of a retrospective analysis. A retrospective study design is prone to selection, performance, and reporting bias. However, long-term outcomes, such as tooth loss, are often not feasible to assess prospectively. Furthermore, we are not able to provide exact numbers on patients lost to follow-up. Every effort was made to include all patients in the practice who received root-resective therapy. However, due to the retrospective nature of this analysis and the fact that the legal obligation to retain medical data covers only a period of 10 years in Germany, it is not possible to ensure that all patients who underwent this treatment were identified. But retention rate of patients to their dentist is very high in Germany (about 90%), in rural areas probably the highest [37]. The strength of this study lies in the homogeneity of treatment: all procedures were performed by the same dentist. On the other hand, this aspect may also limit transferability of our results because they may be highly influenced by the operator and/or equipment. After root resection, molars had a mean survival time of approximately 20 years. Hence, this study provides important information about what is possible in daily practice under the outlines of public health care, when care is administered at each phase of therapy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study formal consent was not required.

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