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Published in:
JOURNAL OF DENTISTRY

DOI:
10.1016/j.jdent.2021.103611

Journal of Dentistry 108 (2021) 103611

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Survival of molar teeth in need of complex endodontic treatment: Influence of the endodontic treatment and quality of the restoration

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ARTICLE INFO

Keywords:
Composite resins
Crowns
Dental restoration
Permanent
Root canal therapy
Tooth loss
Tooth
Nonvital

ABSTRACT

Objectives: The objective of this retrospective practice-based study was to evaluate the survival of molar teeth and endodontic success after complex endodontic treatment up to 89 months.

Methods: Endodontically (Endodontic Treatment Classification (ETC) scores II and III) treated first and second molars treated between January 2011-October 2017 within a referral setting were included. Open apices, combined surgical treatment, ETC score I, patients <18 years or with an ASA-score >2 were excluded. Cumulative survival estimates and Cox regression analysis were performed for tooth survival and endodontic healing according to the Glossary of Endodontic Terms. Restoration quality was assessed using the FDI criteria. Alpha was set at 0.05.

Results: 279 endodontically treated molars in 245 patients were included for survival analysis and 268 molars for endodontic success. After 89 months, the cumulative survival was 91.7 % [95 % CI: 86.8 %–94.9 %]. Absence of adjacent teeth and deviance in root canal morphology significantly decreased the probability of tooth survival. Cumulative endododontic healing rates after 48 and 89 months were 82.2 % [95 %CI: 75.7 %–87.1 %] and 51.1 [95 % CI: 20.2 %–75.5 %] respectively. Deviance in root canal morphology and inadequate coronal seal significantly decreased the probability of endodontic healing. Indirect restorations obtained higher esthetic and biological FDI scores, however no difference between direct and indirect restorations was found concerning the functional FDI score.

Conclusions: After 89 months, cumulative survival of molars in need of complex endodontic treatment was 91.7 % [95 % CI: 86.8 %–94.9 %].

Clinical significance: Within daily clinical practice, the dilemma of performing a complex endodontic (re)treatment or to explore other treatment options for molar teeth in need of reintervention is still urgent. Tooth survival of molar teeth with complex endodontic (re)treatment seems satisfactory up to 89 months.

1. Introduction

The goal of root canal therapy is to clean the root canals and reduce the bacterial load, in order to create an asymptomatic and stable tooth complex. Due to the complex anatomy of the root canal system, which can hinder complete cleaning, inflammation can persist or reoccur after some years and retreatment might be necessary. Endodontic retreatment is more complex and negatively influences the endodontic healing, often necessitating referral to a specialist setting [1].

Besides endodontic treatment the quality of the final restoration plays an important role in endodontic healing and tooth survival [2,3]. Several restorative factors improve the prognosis for tooth survival of endodontically treated teeth, such as a cusp coverage restoration, the presence of mesial and distal contacts and type of tooth [3]. The odds for tooth retention of endodontically treated non-molar teeth was 1.26 (95 % CI: 1.01–1.41) times greater than for molar teeth. In case of

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https://doi.org/10.1016/j.jdent.2021.103611
Received 17 December 2020; Received in revised form 11 February 2021; Accepted 17 February 2021
0300-5712/

endodontically treated teeth, the loss of hard tissue due to fracture or caries is often the main cause for extraction, ranging from 46.4%–63.8% of the cases [4,5].

Besides tooth retention, the endodontically treated tooth should be free of inflammation. Endodontic healing can be evaluated by a combination of clinical and radiographic examinations. According to the Glossary of Endodontic Terms by the American Association of Endodontists, endodontic treatment outcome can be assessed as healed, healing or nonhealed [6]. When there are no clinical symptoms such as pain, palpation sensitivity, localized pockets, sinus tracts or mobility and radiographically there is no periapical pathosis, the case is considered 'healed'. Radiographically, endodontic healing can be assessed using using the Periapical Index (PAI) [7].. It may take several years before a periapical radiolucency has resolved completely. In a consensus report of the European Society of Endodontology, a period of 4 years after endodontic treatment is advised to assess post treatment disease [8]. Therefore, a reduction in the size of a periapical radiolucency is a sign of endodontic 'healing'. When there are clinical symptoms or when there is no difference or an increase in size of the periapical radiolucency, a case is considered 'nonhealed' [9].

Several variables influence the endodontic healing process. Apart from the type of root canal treatment (primary or secondary treatment), the prognosis for endodontic healing is further influenced by six factors [10]: 1) the presence of a preoperative radiolucency, 2) presence of complicating operative factors (e.g. broken instruments or perforations), 3) quality of the coronal restoration, 4) distance of the root canal filling to the radiological apex of the tooth, 5) preservation of the root canal morphology and 6) compactness of the root canal filling. The last three factors can be summarized as the 'technical quality' after endodontic treatment. A root canal therapy of good technical quality means that the canal filling was compact, ended within 0−2 millimeters of the apex and the morphology was preserved.

In order to assess the difficulty of the endodontic treatment, guidelines were developed for the general practitioner: the Endodontic Treatment Classification score (ETC) [11]. This guideline aids the general practitioner when to refer a patient to an endodontic specialist. The ETC scale divides the level of difficulty of the endodontic treatment into three classes. Class I indicates an endodontic treatment of average risk, with limited preoperative concerns. A molar tooth with 3 canals without calcified canals or root curvatures and easy to isolate with rubber dam is an example of an ETC class I score. Class II represents a high risk of complications during the endodontic procedure and achieving a predictable treatment outcome will be difficult for an experienced clinician. A molar tooth with >3 canals, moderate curvature of the roots (10°-30°) and calcified canals is considered ETC class II. When scored as a class III, there is a very high risk of procedural complications and advanced knowledge and specific instruments are needed to achieve a predictable treatment outcome. A molar tooth in need of retreatment and the presence of a broken instrument is an example of a ETC class III.

The primary objective of this retrospective practice-based study was to evaluate the survival of molar teeth with ETC scores of II and III within a referral setting with a minimum service time of the root canal treatment of 12 months. Secondary objectives were to evaluate the quality of the coronal seal, the restoration and the endodontic treatment. The null hypothesis was that the type of endodontic treatment, the ETC score and the quality of the coronal seal would have no influence on tooth survival. Secondary hypothesis was that there would be no difference in restoration quality between the direct and indirect restorations.

2. Material and methods

Endodontically treated maxillary and mandibular first and second molars treated between January 2011 and October 2017 were included in this study. In this period, a total of 416 root canal treatments were performed on endodontically treated molars by two dentists in a referral setting limited to endodontics. Inclusion criteria were molar teeth with a primary or secondary root canal treatment referred to and treated at the dental department of the Martini Hospital Groningen, patients older than 18 years of age and with an American Society of Anaesthesiologists (ASA) score of ≤2. M teeth with open apices, combined non-surgical and surgical treatment, an ETC score of 1 or patients younger than 18 years of age or with an ASA-score >2 were excluded (Fig. 1).

2.1. Endodontic procedure

All endodontic procedures were performed under the microscope (OPMI Pico; Zeiss, Oberkochen, Germany) and rubber dam isolation (Isodam heavy; Sigma Dental, Handewitt, Germany) by two experienced dentists in endodontic (re)treatment in a referral clinic. After endodontic opening, working length was determined using an electronic apex locator (Root ZX II; Morita, Osaka, Japan). Root canals were shaped up to working length using hand files (ISO 6–20; Ready Steel K-file; Dentsply Maillefer, Tulsa, Oklahoma, USA) and a rotary file system (Protaper; Dentsply Sirona, York, Pennsylvania, USA) according to the instructions of the manufacturer. In endodontic retreatment cases, rotary files D1/D2/D3 (Protaper system, Dentsply Sirona) were used. Root canals were irrigated using a 2% sodium hypochlorite solution (Reymerink, 's-Gravelande, the Netherlands) and 17 % EDTA (Calasept EDTA, Directa, Väsby, Sweden). As a final irrigation protocol, sodium hypochlorite was activated using ultrasonic passive irrigation during 20 s, which was repeated for three times. After drying the canals using paper points, a root sealer (AH26 Root canal sealer, Dentsply Sirona) was applied to the canal walls. An apical gutta-percha (Protaper system, Dentsply Sirona) plug was created using master cone which was sealed off within 5 mm of working length (with the Continuous Wave of Obturation Technique). The remaining part of the root canal was filled using warm gutta-percha (BeeFill 2 in.; VDW GmbH, München, Germany) with a back-fill technique. A post-endodontic build-up was created using a sixth generation bonding agent (Clearfil SE Bond; Kuraray Noritake, Okayama, Japan) a bulk-fill composite (Surefil SDR flow; Dentsply Sirona, Milford, USA) to seal de coronal canal entrance and a nanohybrid composite (Filtek Supreme XTE; 3 M ESPE, Seefeld, Germany) via the incremental layering technique. After the endodontic treatment, an intraoral radiograph was taken to evaluate the post-operative endodontic quality.

2.2. Recall appointment

As a part of regular care, 9–12 months after endodontic intervention a recall appointment was planned to assess the healing process. During this recall appointment, patients were asked about possible symptoms. Endodontic diagnostics, both clinically (percussion, palpation, probing) and radiologically, were carried out. In case of symptoms, patients were rescheduled for an appointment after 12 months. After the recall appointment, patients returned to their general dentist for regular care. Because of the referral setting, after the recall appointment no further follow-up was present. In order to assess tooth survival, the healing after a period of 9–12 months and the quality of the restoration, an additional appointment was necessary. In a systematic review of tooth survival for all types of endodontically treated teeth, the cumulative survival rate was 86.7 % after 8–10 years. [3] In order to estimate a survival proportion of 86.7 % endodontically treated molars with 95 % confidence and a margin of error of 3.5 %, 362 endodontically treated molars needed to be included. This study was approved by the Medical Ethical Committee of the Martini hospital and registered in the national trial register (NL7153). Informed consent was obtained from all patients attending the clinic. Patient, pre-, post-endodontic and restorative variables were listed (see Table 1). Four observers (A.R., C.F., J.B. and M. K.), were calibrated for the endodontic evaluations. Light pictures were taken from occlusal, lingual and buccal side of the endodontically treated tooth using a Digital Single Lens Reflex camera (Canon 80D, 100

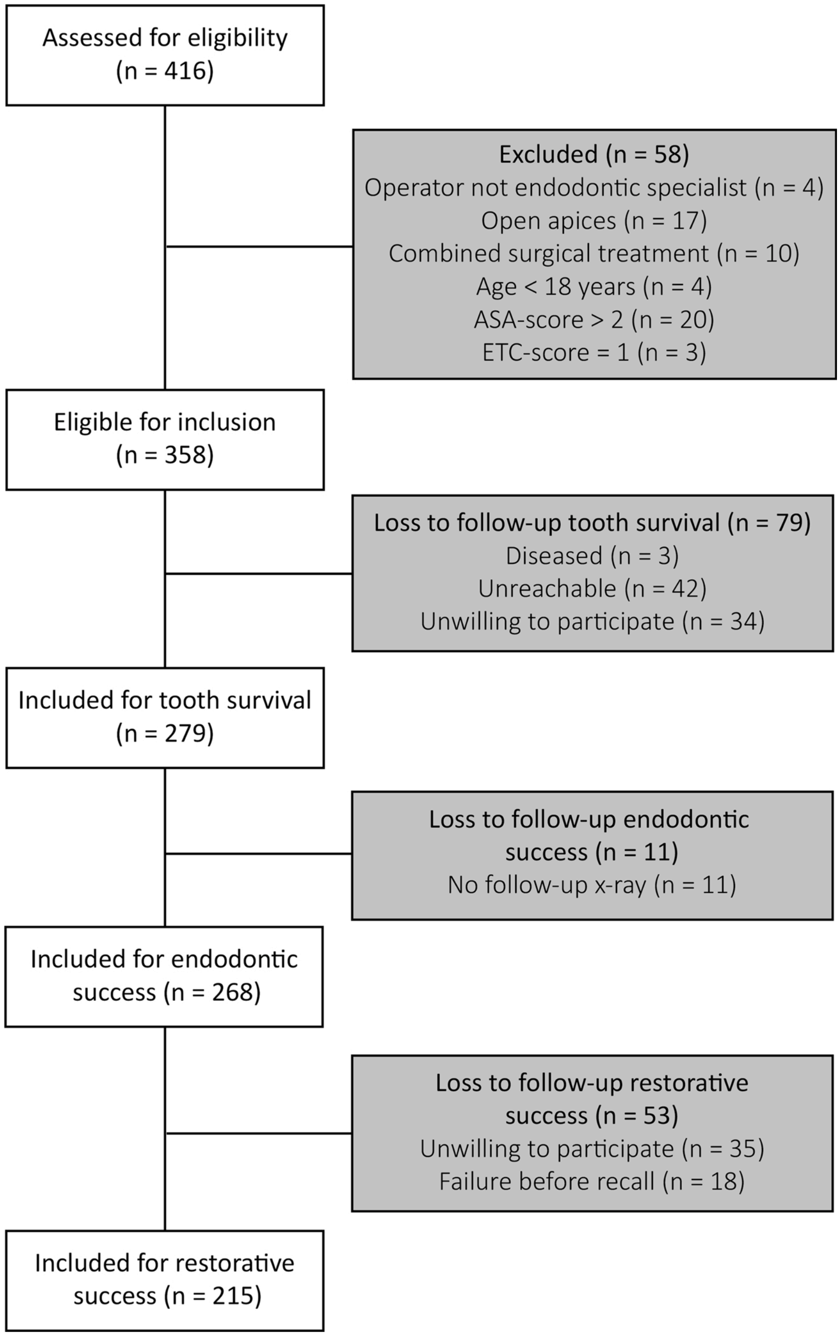

Fig. 1. Flow chat of inclusion process of endodontically treated molar teeth.

mm F2.8 macro; Canon Incorporation, Tokyo, Japan). When the radiograph was older than 2 years, the patient experienced clinical symptoms, there was a radiolucency present on the latest radiograph or when the coronal seal was compromised, a new radiograph was taken. Two observers were present during the appointment, one of whom was the same (M.K.) for all clinical observations. A joined decision was taken concerning findings during the clinical examination.

When a patient was unable to attend, an anamnesis was taken over the phone and patients' permission was asked to contact the general practitioner about the clinical and radiographic status of the tooth. For endodontic healing, the date of the latest radiograph in the chart of the general practitioner or the registration at the hospital was noted.

2.3. *Patient variables*

Patient variables included age, caries risk and parafunction. When a patient did not experience any caries during the two years before the recall appointment, the patient was considered as a low caries risk patient. When a patient had one caries lesion, the patient was considered as medium risk and when two or more lesion developed during the last two years, patients were scored as high caries risk.

2.4. *Endodontic variables*

Pre-endodontic variables consisted of the DETI/ETC score (I/II/III), endodontic diagnosis (irreversible pulpitis / apical periodontitis), number of root canals treated, preoperative complications (broken instrument, perforation, obliteration), preoperative radiolucency and the

Table 1
Variables included in the study. ETC: Endodontic Treatment Classification. *Total number of endodontically treated molars n = 268.

Factor	Level	Number (%)
Operator	1	238 (85 %)
	2	41 (15 %)
Caries risk	Low	155 (55 %)
	Medium	78 (28 %)
	High	44 (16 %)
	Unknown	2 (1%)
Parafunction	Yes	85 (31 %)
	No	190 (68 %)
	Unknown	4 (1%)
Gender	Male	125 (45 %)
	Female	154 (55 %)
Jaw	Upper	145 (52 %)
	Lower	134 (48 %)
Number of canals treated	3	42 (15 %)
	4	237 (85 %)
ETC score	II	49 (18 %)
	III	230 (82 %)
Preoperative radiolucency	Yes	237 (85 %)
	No	42 (15 %)
Preoperative complicating factor	Yes	125 (45 %)
	No	154 (55 %)
Type of endodontic treatment	First	128 (46 %)
	Retreatment	151 (54 %)
Technical quality endodontic treatment	Adequate	179 (64 %)
	Inadequate	100 (36 %)
Restoration type follow-up	Direct	127 (46 %)
	Indirect	147 (52 %)
	Unknown	5 (2%)
Cusp coverage follow-up	Yes	179 (64 %)
	No	87 (31 %)
	Unknown	13 (5%)
Coronal seal follow-up	Adequate	230 (82 %)
	Inadequate	36 (13 %)
	Unknown	14 (4%)
Endodontic healing*	Healed	175 (65 %)
	Healing	49 (19 %)
	Nonhealed	44 (16 %)

type of endodontic treatment (initial/retreatment). Post-endodontic variables were the presence of clinical symptoms (anamnesis, percussion, palpation testing and probing), healing (healed/healing/nonhealed), postoperative radiolucency and the technical quality of the endodontic treatment as scored on a radiograph. Healing was assessed using the endodontic treatment outcomes as was defined the Glossary of Endodontic Terms by the American Association of Endodontists. A case was considered 'healed' when no clinical symptoms and no periapical radiolucency was present. A case was considere 'healing' when no clinical symptoms were present and the peri-apical radiograph showed a reduction in size of the radiolucency as compared to baseline. When clinical symptoms were present or the radiolucency did not reduce or increased in size or intervention was necessary (extraction, non-surgical or surgical (re)treatment), a case was considered as 'nonhealed'. Postoperative radiolucency was assessed using the Periapical Index (PAI). [7] A PAI $\geq$ 3 was scored as a postoperative radiolucency. When the obturation of the root canals was compact (no voids), followed the original morphology and finished within 0−2 mm of the radiographic apex, the technical quality was scored as adequate. When one of the criteria was inadequate, the overall technical quality was judged to be inadequate.

2.5. Restorative variables

Restorative variables were the jaw, presence of adjacent teeth, cusp coverage of all remaining cusps, the quality of the coronal seal and restoration quality as scored by the FDI criteria [12], restoration surfaces, type (direct/indirect) and material (composite/amalgam/glass ceramic/PFM/zirconia). The FDI criteria grades the restoration on esthetic, functional and biological aspects. When scored in the range of 'clinically excellent' to 'clinically sufficient', there is no need for the restoration to be replaced. A score of 'clinically unsatisfactory' suggest replacement of the restoration for prophylactic reasons and a score of 'clinically poor' indicates a necessary replacement. Observers were calibrated for the FDI criteria using the online calibration tool www.e-calib.info.

2.6. Database and statistics

Data was stored in an online electronic data capture software (REDcap; https://projectredcap.org) and analyzed using IBM SPSS 24 statistic software package. One observer (M.K.) verified the database 2 months after completion of the study and scored the presence of a periapical radiolucency and the technical quality on the radiograph. Differences between observers (M.K. and A.R./C.F./J.B.) were noted and a Cohen's Kappa was calculated. Patient (age, caries and parafunctional risk), pre-endodontic (number of canals, type of treatment), post-endodontic (radiolucency) and restorative (type of restoration at recall, cuspal coverage, FDI criteria) variables were presented using descriptive statistics. Kaplan-Meier survival estimates for tooth survival and endodontic healing were calculated after 24 months, 48 months and after the maximum observation time of 89 months with 95 % confidence intervals. A case was censored when no event happened before the last follow-up. For tooth survival, extraction was considered an event. For endodontic healing, cases defined as 'healed' and 'healing' were clustered and 'nonhealed' cases were considered an event. Predictor variables with p-values <0.15 based on univariate analysis were entered into a Cox proportional hazards regression, after checking the proportional hazard assumption and correlation between the variables. For the difference in the esthetic, functional and biological FDI criteria between direct and indirect restorations a Fisher-Freeman-Halton Exact test was performed. Alpha was set at 0.05 in all aforementioned tests.

3. Results

A total of 416 M teeth were assessed for eligibility. After review, a total of 358 M teeth met the inclusion criteria, of which 79 were lost to follow-up for tooth survival. For the assessment of endodontic healing, additionally 11 molars were lost to follow-up (Fig. 1). This resulted in the inclusion of 279 endodontically treated molars in 245 patients (age: 54 $\pm$ 14 years; 125 males, 154 females) for survival analysis and 268 molars for endodontic healing. Mean follow-up time for tooth survival was 44.6 $\pm$ 20 months (range: 2–89 months; 6 early failures occurred within 12 months) and for endodontic healing 42.4 $\pm$ 21.5 months (range: 2–89 months; 6 early failures occurred within 12 months). An overview of the inclusion process and reasons for loss-to-follow up are depicted in Fig. 1. Patient, pre-, post-endodontic and restorative characteristics are listed in Table 1.

3.1. Survival of endodontically treated molars

Of the 279 endodontically treated molars, 18 molars (in 18 patients) were extracted due to periodontitis (n = 2), persistent endodontic inflammation (n = 10), vertical root fracture (n = 5) or for unknown reasons (n = 1). Of the failures, 7 molars received initial endodontic treatment and 11 molars received secondary endodontic treatment. Concerning ETC score, 3 failures occurred in class II and 15 failures in class III molars. The cumulative survival for the endodontically treated molars was 96.4 % [95 % CI: 93.4 %–98.0 %; number at risk = 234], 92.7 % [95 % CI: 88.4 %–95.5 %; number at risk = 113] and 91.7 % [95 % CI: 86.8 %–94.9 %] after respectively 24, 48 months and 89 months. In Table 3 cumulative survival estimates are listed according to the type of endodontic treatment and the ETC score.

3.2. Influence of predictor variables on tooth survival

Table 2 summarizes the hazard ratios corresponding 95 % confidence intervals of the predictor variables on tooth survival for both the univariate and multivariate Cox proportional hazard regression analysis. The number of adjacent teeth (0 versus 1 or 2), the quality of the coronal seal at follow-up (adequate/inadequate), parafunction and deviance of the endodontic treatment from the root canal morphology (present/absent) were included in the multivariate analysis. When the endodontic treatment deviated from the root canal morphology, the tooth was on average 5.31 times more likely to be extracted than when root canal morphology was followed ($p = 0.00$; Fig. 2). When no adjacent teeth were present, the tooth was 3.18 times more likely to be extracted than when ≥1 adjacent teeth were present ($p = 0.04$; Fig. 3). Teeth without adjacent teeth were part of a bridge (n = 17) or the last tooth in the arch (n = 8).

3.3. Endodontic healing

Cumulative endodontic healing estimates were 94.4 % [95 % CI: 90.7 %–96.6 %; number at risk = 205], 82.2 % [95 %CI: 75.7 %–87.1 %; number at risk = 100], 51.1 % [95 % CI: 20.2 %–75.4 %] after 24, 48 and 89 months. In Table 3 cumulative endodontic healing estimates are listed according to the type of endodontic treatment and the ETC score.

Table 2
Overview of cumulative estimates for tooth survival and endodontic healing (% [95 %CI] after 24, 48 and 89 months. Cumulative estimates are listed for overall performance and according to type of treatment (initial or retreatment) and ETC score (class II or III).

Time	Cumulative tooth survival % [95 %CI]	Number at risk (n)	Cumulative endodontic healing % [95 % CI]	Number at risk (n)
After 24 months				
Overall	96.4 [93.4–98.0]	234	94.4 [90.7–96.6]	205
Initial treatment	96.0 [90.8–98.3]	111	95.6 [89.8–98.2]	97
Retreatment	96.7 [92.2–98.6]	122	93.3 [87.5–96.5]	107
ETC class II	95.8 [84.4–98.9]	40	94.9 [81.2–98.7]	33
ETC class III	96.5 [93.1–98.2]	19	94.3 [90.1–96.7]	171
After 48 months				
Overall	92.7 [88.4–95.5]	113	82.2 [75.7–87.1]	100
Initial treatment	94.1 [88.0–97.2]	62	85.6 [76.2–91.5]	53
Retreatment	91.3 [83.8–95.4]	50	78.9 [68.8–86.1]	46
ETC class II	93.1 [79.0–89.5]	193	84.4 [66.1–93.3]	14
ETC class III	92.7 [87.7–95.7]	94	81.8 [74.5–87.2]	86
After 89 months				
Overall	91.7 [86.8–94.9]		51.1 [20.2–75.4]	
Initial treatment	94.1 [88.0–97.2]		56.4 [20.1–81.5]	
Retreatment	89.2 [80.1–94.3]		61.0 [44.5–74.0]	
ETC class II	93.1 [79.9–97.8]		87.6 [69.8–95.3]	
ETC class III	91.5 [85.7–95.0]		32.7 [2.0–72.6]	

3.4. Influence of predictor variables on endodontic healing

Tables 3 and 4 summarize the hazard ratios corresponding 95 % confidence intervals of the predictor variables on endodontic healing for both the univariate and multivariate Cox proportional hazard regression analysis. Parafunctional habits, type of endodontic treatment, obturation length, deviance of the endodontic treatment from the root canal morphology and the quality of the coronal seal at follow-up all had p-values <0.15. There was a significant correlation between obturation length and deviance from the root canal morphology ($r(276) = 0.39$, $p = 0.00$) and obturation length was excluded from the multivariate analysis. When the coronal seal was not adequate, the endodontic treatment was on average 2.19 times more likely to result in nonhealing ($p = 0.03$). Deviance from the root canal morphology also resulted in an increased risk for nonhealing (hazard ratio: 2.52 [95 % CI: 1.23–5.15]; $p = 0.01$).

3.5. Inter- and intra-observer reliability

Inter-observer agreement for the presence of a peri-apical radiolucency was 0.82 (n = 70; A.R. versus M.K.), 0.76 (n = 64; C.F. versus M. K.) and 0.83 (n = 56; J.B. versus M.K.). Intra-observer agreement for the presence of a peri-apical radiolucency was 0.83 (n = 76; M.K.). Inter-observer agreement for the technical quality of the endodontic treatment was 0.76 (n = 77; A.R. versus M.K.), 0.84 (n = 66; C.F. versus M.K.) and 0.77 (n = 56; J.B. versus M.K.). Intra-observer agreement for the technical quality was 0.75 (n = 75; M.K.).

3.6. Quality of the coronal restoration

Of the direct restorations, 99.2 % were made of composite and 0.8 % of amalgam. For the indirect restorations, 14.3 % zirconia, 29.9 % glass ceramic and 55.8 % porcelain-fused-to-metal (PFM) were used. In Fig. 4 the number of restored surfaces per restoration type are summarized. Figs. 5–7 graphically depict the FDI esthetic, functional and biological scores for the direct and indirect restorations. There was a significant association between the type of restoration and the esthetic FDI score (Fisher-Freeman-Halton Exact; $p < 0.00$). Indirect restoration was more frequently scored as esthetically excellent, good or acceptable than the direct restorations. There was no significant association between the type of restoration and the functional FDI score (Fisher-Freeman-Halton Exact; $p = 0.24$). For the FDI biological criteria, there was a significant association between the type of restoration (Fisher-Freeman-Halton Exact; $p = 0.01$). Indirect restorations were more often scored biologically excellent as compared to the direct restorations.

4. Discussion

The primary objective of this retrospective practice-based study was to evaluate the survival of molar teeth in need of complex endodontic treatment within a specialist setting with a minimum service time after the root canal treatment of 12 months. The null hypothesis that the type of endodontic treatment, the ETC score and coronal seal would have no influence on tooth survival, was accepted. In a systematic review, predictors for endodontically treated teeth negatively influencing tooth survival were no crown restoration after endodontic treatment (HR = 3.92, 95 %CI: 3.54–4.33), no or one adjacent tooth (HR = 3.08, 95 %CI: 1.78–5.32), tooth functioning as an abutment for removal or fixed prosthodontics (HR = 1.70, 95 %CI: 1.31–2.20) and molar teeth (HR = 1.19, 95 %CI: 1.01–1.41) [3]. In the present study the number of adjacent teeth was also a significant predictor for tooth survival (hazard ratio: 3.18 [95 %CI: 1.04–9.7]. This is in accordance with the case-control study of Caplan et al. [13], where the cases had significant fewer contacts (odds ratio 2.7 795 %CI: 1.4–5.1]). They present four theories which could explain the relationship between tooth extraction and the number of proximal surfaces. First, the single tooth probably endures more loading during chewing, than when adjacent teeth would

Table 3
Hazard ratios with 95 % confidence intervals of predictor variables (reference category) for **tooth survival** in the univariate analyses[1] and the multivariate Cox proportional hazard regression[2] analysis.

Predictor	Hazard ratio[1]	95 % CI[1]	p-value[1]	Hazard ratio[2]	95 % CI[2]	p-value[2]
Patient characteristics						
• Caries risk (low)	0.82	0.32−2.12	0.68			
• Parafunction (no)	2.23	0.84−5.94	0.11	1.85	0.67−4.91	0.24
• Age	1.01	0.97−1.04	0.74			
Tooth characteristics						
• Operator (1)	0.41	0.05−3.07	0.38			
• Jaw (upper)	1.09	0.43−2.74	0.96			
• Adjacent teeth (n≥1)	3.55	1.26−9.96	0.02	3.18	1.04−9.70	0.04
Endodontic characteristics						
• ETC score (III)	1.04	0.30−3.58	0.96			
• Preoperative radiolucency (no)	0.96	0.28−3.32	0.95			
• Preoperative complicating factor (no)	1.45	0.57−3.68	0.43			
• Type of endodontic treatment (first)	1.45	0.56−3.74	0.44			
• Obturation length (adequate)	0.98	0.35−2.74	0.96			
• Compact obturation (adequate)	1.32	0.30−5.77	0.71			
• Deviance from canal morphology (absent)	5.39	2.09−13.9	0.00	5.31	1.95−14.77	0.00
Restorative characteristics						
• Type of restoration (direct)	1.63	0.61−4.35	0.33			
• Coronal seal (adequate)	2.56	0.91−7.19	0.07	1.07	0.29−4.04	0.91
• Cusp coverage (no)	1.98	0.56−6.95	0.29			

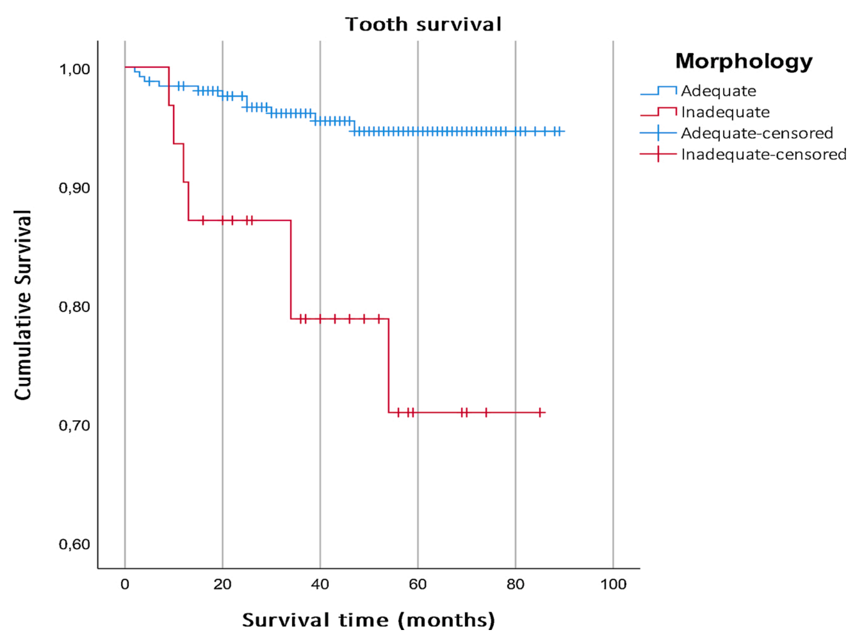

Fig. 2. Survival curve for tooth survival according to deviance of root canal morphology after endodontic (re)treatment.

be present. Second, abutments for a fixed dental prosthesis might be more difficult to clean as compared to a natural contact point. Third, when a removable partial denture is present, the abutment tooth is under stress due to the clasp. The fourth theory concerns the patient factor: a patient with more missing teeth might have a greater risk of developing oral disease, or values oral health less than a patient with fewer missing teeth. In the current study, most teeth were either part of a bridge or had a diastema without a removable partial denture.

A new predictor was a deviance in the morphology of the root canal during endodontic (re)treatment, such as a ledge or a perforation. A ledge hinders complete cleaning of the root canal system, which increases the risk of endodontic inflammation. A perforation weakens the root due to loss of hard tooth tissue.

After the maximum observation time, 89 months, the cumulative survival of endodontically treated molars was 91.7 % [95 % CI: 86.8 %–94.9 %]. The cumulative survival rate in a systematic review pooling 1.464.759 endodontically treated teeth (all tooth types) with primary endodontic treatment was 86.7 % (95 %CI: 81.6 %–91.8 %) after 8–10 years [3]. When comparing this to the survival rate found in this study, it can be considered a satisfactory result, since only endodontically treated molars with an ETC score of II and III were included and the majority of the molars were endodontically retreated. In a prospective cohort study, a survival rate of 79 % was found for 196 endodontically treated teeth over a period of 20 years [14]. In a retrospective study a survival rate of 94.1 % for 1960 posterior endodontically treated teeth after a mean service time of 27 months was reported [15]. Comparison of the two aforementioned studies with the current study however is difficult, since no 95 % confidence intervals were given. For 174 molars endodontically treated by 12 general practitioners, the crude failure rate per 100 years with a root filled molar was 2.7 [16]. For the current study, the crude

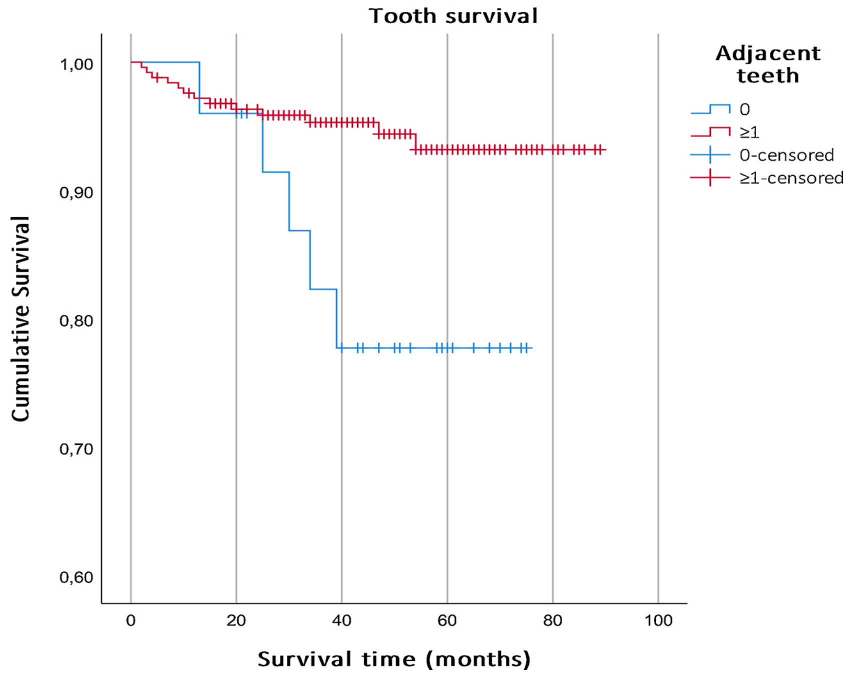

Fig. 3. Survival curve for tooth survival according to number of adjacent teeth.

Table 4
Hazard ratios with 95 % confidence intervals of predictor variables (reference category) for **endodontic healing** in the univariate analyses[1] and the multivariate Cox proportional hazard regression[2] analysis.

Predictor	Hazard ratio[1]	95 % CI[1]	p-value[1]	Hazard ratio[2]	95 % CI[2]	p-value[2]
Patient characteristics						
• Caries risk (low)	1.31	0.72–2.38	0.38			
• Parafunction (no)	1.68	0.91–3.12	0.10	1.54	0.82–2.86	0.18
• Age	1.00	0.99–1.02	0.58			
Tooth characteristics						
• Operator (1)	0.70	0.21–2.31	0.56			
• Jaw (upper)	0.99	0.55–1.78	0.96			
Endodontic characteristics						
• ETC score (III)	1.88	0.67–5.31	0.23			
• Preoperative radiolucency (no)	1.14	0.51–2.57	0.75			
• Preoperative complicating factor (no)	0.95	0.53–1.73	0.87			
• Type of endodontic treatment (first)	1.64	0.88–3.05	0.12	1.56	0.80–3.04	0.19
• Obturation length (adequate)	1.95	1.07–3.55	0.03			
• Compact obturation (adequate)	0.94	0.42–2.12	0.88			
• Deviance from canal morphology (absent)	2.72	1.37–5.40	0.00	2.52	1.23–5.15	0.01
Restorative characteristics						
• Type of restoration (direct)	0.99	0.55–1.81	0.99			
• Coronal seal (adequate)	2.77	1.45–5.32	0.00	2.19	1.09–4.38	0.03

failure rate per 100 years with a root filled molar was 1.7 (total of 1037 years; 18 failures). Possible explanations for this lower crude failure rate, might be that the endodontic (re)treatments in the current study were performed by two dentists specializing in endodontic treatment. Tooth survival was found to be higher when the endodontic treatment was performed by endodontic specialist as compared to general dentists [15].

The low amount of failures within this study might have resulted in too little power to detect other significant restorative predictors for the survival of endodontically treated molars, such as the type of restoration (direct/indirect) or cuspal coverage. For posterior endodontically treated teeth, placement of a crown was associated with a higher survival rate as opposed to direct restorations [16]. However, the inclusion period of this study was 1998–2003 and it was not clear if the direct restorations were amalgam, composite or glass ionomer. In a recent systematic review about the tooth survival of endodontically treated teeth with direct or indirect restorations [17], 8 studies were included for meta-analysis. The odds ratio for extraction of an endodontically treated tooth was 0.2 (95 %CI: 0.12–0.31) for an indirect restoration as compared to direct restorations. However, for the retrospective studies [18,19] included in the meta-analysis, the distribution of composite, glass ionomer and amalgam fillings is not mentioned. Since there is a shift from amalgam to composite resin to restore posterior teeth [20,21], endodontically treated teeth receive more bonded restorations [22]. Resin composite was also used in the majority (99.2 %) of the direct restorations in the current study. Cuspal coverage, direct or indirect, and preservation of tooth structure might be more important factors than the choice of material alone [22,23]. More clinical trials are needed to

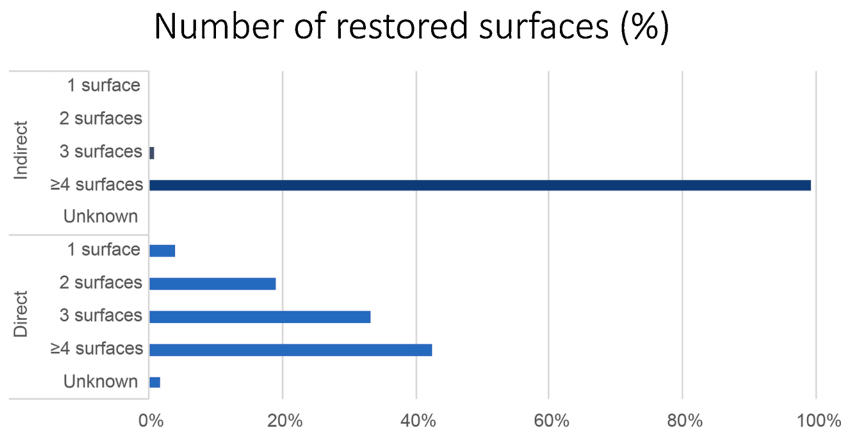

Fig. 4. Number of restored surfaces (%).

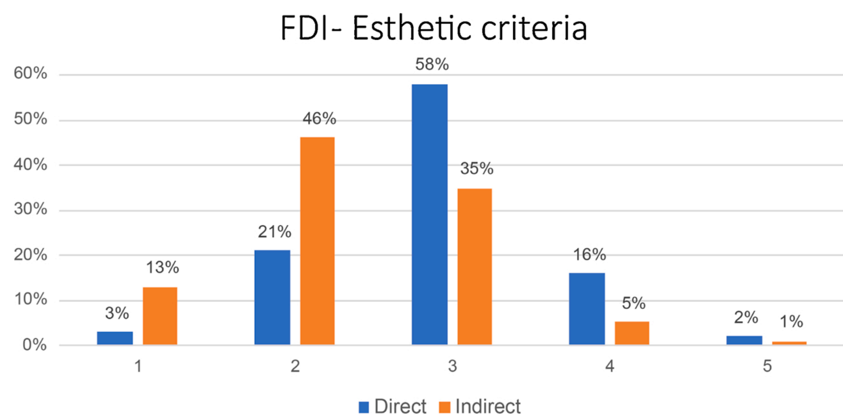

Fig. 5. FDI esthetic score (% of total restoration type) for direct (n = 100) and indirect restorations (n = 115). Score 1: clinically excellent; Score 2: clinically good; Score 3: clinically sufficient; Score 4: clinically unsatisfactory; Score 5: clinically poor.

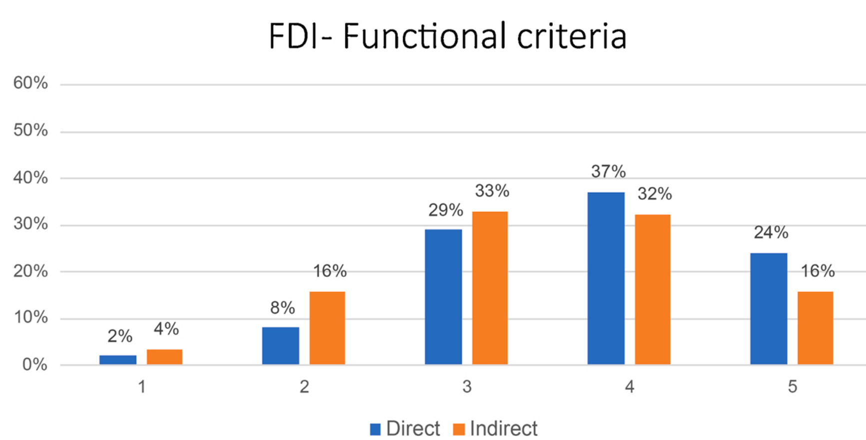

Fig. 6. FDI functional score (% of total restoration type) for direct (n = 100) and indirect restorations (n = 115). Score 1: clinically excellent; Score 2: clinically good; Score 3: clinically sufficient; Score 4: clinically unsatisfactory; Score 5: clinically poor.

investigate the influence of bonded restorations with cuspal coverage, direct or indirect, on the survival of endodontically treated teeth. In spite of possibilities of adhesive rehabilitation of endodontically treated teeth, most of the molars in this study received a full contour crown as an indirect restoration. A partial indirect restoration might be beneficial to preserve tooth structure. Endodontic treatment did not influence the success rate of partial lithium disilicate restorations in a clinical evaluation of 765 indirect restorations [24].

In the current study, the aimed sample size of 362 was not accomplished. No finite population correction factor was used, in order to generalize the survival estimates for endodontically treated molars. When applying the finite population correction factor for the referral setting (n = 416 molars), a total of 194 M teeth needed to be included to estimate the tooth survival within the referral setting. Tooth survival estimates found in this study are therefore a reliable reflection within the referral setting.

In the present study, the main reason for extraction was persistent endodontic inflammation. This is in contrast with observational studies

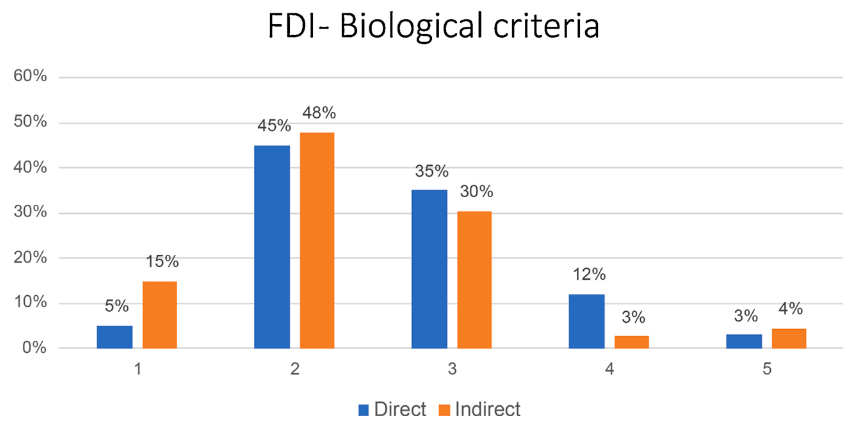

Fig. 7. FDI biological score (% of total restoration type) for direct (n = 100) and indirect restorations (n = 115). Score 1: clinically excellent; Score 2: clinically good; Score 3: clinically sufficient; Score 4: clinically unsatisfactory; Score 5: clinically poor.

[4,5]. Extraction of endodontically treated teeth due to loss of hard tissue because of caries ranged from 46.4%–61.4% and tooth fracture from 11.7%–32.1%. Only 10.7%–12.1% of the extractions was due to persistent endodontic inflammation. There are several reasons for this difference. Because of the retrospective nature of this study, general dentists received no instructions concerning the possible reasons for extraction. For example, when a deep caries lesion resulted in endodontic reinfection and subsequent extraction, there is a high change that only the endodontic inflammation was noted in the patient record, instead of the caries lesion leading to the endodontic inflammation. Another reason could be related to the molar teeth, where complete cleaning of the root canal system can be more difficult than non-molar teeth. In the observational studies, the reasons for extraction of molar and non-molar teeth are often pooled.

In two systematic reviews, a meta-analysis was performed for endodontic success according to the strict and loose criteria. For primary endodontic treatment, pooled weighted success rates for strict and loose criteria are 74.7 % (95 %CI: 69.8–79.5 %) and 85.2 % (95 %CI: 82.2–88.3 %) [25,26]. Pooled weighted success rates for endodontic retreatment based on strict and loose criteria are 76.7 % (95 %CI: 73.6–89.6 %) and 77.2 % (95 %CI:61.1–88.1 %) [27]. When comparing the 95 % confidence intervals, the cumulative healing rates after 48 months found in the current study are comparable for the primary and secondary endodontic treatment. However, after 89 months there is a decrease in the cumulative endodontic healing estimates. This is mainly due to a large amount of censoring, as can be seen by the wide range of the 95 % confidence intervals. In case of a large amount of censoring, one late failure can greatly influence the Kaplan-Meier cumulative healing estimate. Another possible explanation could be that in meta-analyses, all tooth types are pooled together, whereas in this study, only molars are concerned. In the multivariate analysis, deviance from the root canal morphology and inadequate coronal seal were significant predictors for endodontic healing. This is in line with a systematic review [10]. Other factors influencing endodontic healing are the presence of a preoperative radiolucency, complicating operative factors, the distance of the root canal filling to the radiological apex of the tooth and compactness of the root canal filling. In the current study, probably these factors are accounted for within the variable deviance of root canal morphology. When there is a complicating factor, there is a higher risk of deviance from the root canal morphology and obturation length might be inadequate. Furthermore, there was a significant correlation between the deviance and obturation length. A preoperative radiolucency was not a significant predictor in the current study. Upon reviewing the results, the majority of the cases with inadequate morphology did not present with a preoperative radiolucency.

Secondary hypothesis was that there would be no difference in restoration quality between the direct and indirect restorations. Indirect restorations performed better than direct restorations according to the FDI esthetic and biologic criteria. There was however no difference between the two types of restorations concerning the functional score. Because of the cross-sectional nature of this part of the study, the service time of the restorations was not taken into account.

5. Conclusions

After 89 months, the cumulative survival of molars in need of complex endodontic treatment was 91.7 % [95 % CI: 86.8 %–94.9 %]. Predictors lowering the probability of tooth survival were the absence of adjacent teeth and a deviance in root canal morphology. Type of endodontic treatment, ETC score and quality of the coronal seal did not influence tooth survival significantly. Indirect restorations performed with higher esthetic and biological FDI scores, whereas there was no difference between direct and indirect restorations concerning the functional FDI score.

CRediT authorship contribution statement

Maurits C.F.M. de Kuijper: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing - original draft. **Eric W. Meisberger:** Conceptualization, Data curation, Resources, Methodology, Visualization, Writing - original draft. **Amarins G. Rijpkema:** Investigation, Project administration, Writing - original draft. **Cathleen T. Fong:** Investigation, Project administration. **Jantien H.W. De Beus:** Investigation, Project administration. **Mutlu Özcan:** Supervision, Writing - review & editing. **Marco S. Cune:** Supervision, Validation, Writing - review & editing. **Marco M. M. Gresnigt:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

This study was supported by a research grant (#2015) of the Dutch society for dental science ’Stichting Bevordering Tandheelkundige Kennis’. The authors acknowledge the research department of the Martini Hospital and the colleagues of the center for dental special care for their support during the logistic part of the study and G. Kuipers, MSc for the opportunity to review her patients.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2021.103611.

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