CLINICAL RESEARCH

Additional Treatment Indicative of an Unfavorable Endodontic Outcome in a Swedish County—A 10-year Observational Study

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ABSTRACT

Introduction: This study's aim was to calculate the incidence of first additional endodontic treatment or extraction as the result of an unfavorable endodontic outcome following orthograde root canal treatment (RCT) performed by general dental practitioners during a 10-year period and to identify possible predictors for outcomes. **Methods:** A randomized cohort of 280 individuals (and as many teeth) with an orthograde RCT was followed for over 10 years. Dental records were reviewed, and individuals were recalled when data were missing. The following terminal events indicative of unfavorable endodontic treatment outcome were orthograde retreatment, surgical endodontics, and tooth extractions exclusively due to endodontic reasons. Selected variables related to individuals and treatment (pre-, intra-, and postoperative) were harvested to analyze possible associations with the terminal events. Unadjusted survival analysis and Cox regression analysis were performed and $P < .05$ was considered statistically significant. **Results:** Terminal events were registered for 22 teeth/individuals and 17 of these were orthograde retreatments. The cumulative 10-year survival of RCTs was 92.7% (standard error 1.7%), with a higher yearly incidence during the first 2 years. The univariate analysis identified 5 factors associated with the outcome. There were too few events to perform a multivariate analysis. **Conclusions:** The mean incidence of additional treatment indicative of unfavorable endodontic outcome was 0.7% per year during the first 10 years, but the mean incidence was greater during the first 2 years. Five factors were associated with an unfavorable outcome; however, confounders cannot be excluded from the associations. *(J Endod 2023;49:267–275.)*

SIGNIFICANCE

The study provides insight on general dental practitioners effectiveness in performing root canal treatments by focusing on cause-specific survival of treatment. It presents the additional treatments that were performed to as well as indicating some potential prognostic factors.

KEY WORDS

Analysis; survival; dentistry; public health; prognosis; tooth extraction; retreatment

Classically, endodontic biological goals were set as a combination of radiographic normality and absence of symptoms, a proxy for absence of apical periodontitis[1]. Recently, more patient-centered outcomes have been proposed such as avoidance of tooth extractions or a combination of tooth extractions and the need for additional endodontic treatments[2]. For patients, an endodontic treatment is unfavorable when additional endodontic treatment is needed. Orthograde retreatments and surgical endodontics could salvage and prolong the life of a tooth unsuccessfully treated with a primary root canal treatment (RCT). To the patient, tooth extraction following RCT would be an even more evident sign of a failed treatment. Patients probably can more easily understand tooth survival as a successful outcome than apical healing.

For any patient deciding on or any dentist proposing an RCT, it is relevant to know how long the tooth is anticipated to survive after a completed endodontic treatment. What is the probability of additional endodontic treatments? If an additional treatment is necessary, what type of treatment can be anticipated? Is there a probability of one or several additional treatments? If there is a need for an additional treatment, when will it most likely be needed? Longitudinal studies indicate that tooth loss after RCT seems to be constant for at least the first 10 years, with a yearly incidence of about 2%[3,4].

However, tooth extractions as a direct consequence of endodontic problems seem somewhat unusual and other reasons for extractions of root-filled teeth such as caries and tooth fractures

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predominate[5-10]. Studies, especially for studies retrieving data from registries, on tooth survival following endodontic treatment do not always report the reasons for extractions. When they do report reasons for extractions, authors performing further analysis often ignore them. That is, they still analyze all extracted teeth but do not discriminate teeth extracted for endodontic reasons[4,5,7,11-15]. Unlike a dentist proposing RCT, patients probably have minimal interest in knowing why endodontically treated teeth need to be extracted. Analyses of tooth extractions following RCT are probably a reflection of the overall status of the tooth and any treatments received rather than the specific endodontic treatment.

Thus, to gain knowledge on the actual outcome of RCTs, extractions as the result of endodontic reasons need to be combined with additional endodontic treatments. Such reason-specific survival analysis could potentially lead to knowledge that can be used to improve RCT and predict treatment outcomes. The aim of this study was to chart and calculate the incidence of first additional treatment that is indicative of an unfavorable endodontic outcome following completion of an RCT performed by general dental practitioners (GDPs) over a 10-year period. Another aim was to identify a set of possible predictors for unfavorable outcomes.

MATERIALS AND METHODS

This study was based on the same cohort and observation period used in a previous study[4], where the selection process and the data collection are described in more detail. Briefly, 3676 individuals were eligible as they had undergone at least one completed orthograde RCT by a GDP in a county council clinic in North Bothnia, Sweden in 2006. A random sample of 302 living individuals was provisionally included. In total, 280 individuals did not reject participation and were included, and were retrospectively followed for an observation period of up to 12 years (Fig. 1). One tooth per individual was used in the analyses; that is, if one individual had more than one tooth with a completed RCT during 2006, one of these teeth was randomly selected to be included in the study.

Data Collection

Analog and digital dental records including dental radiographs were retrieved from the clinics; 110 of the analog records could not be fully retrieved as some variables were not available. The data collection period lasted between September 2016 and May 2018.

Initially, the dental records were screened. If follow-up data were lacking in the clinical records, the individuals were called to an examination performed either by one of the authors (SK) or by a caregiver at the nearest dental clinic. During these examinations, follow-up data were collected. Dental records were reviewed thoroughly for relevant potential predictor variables related to the individual, the events of interest, and the preoperative, intraoperative, and postoperative factors (Table 1). For this study, the reason for extraction and retreatment was reviewed with a more detailed assessment of the clinical records. This assessment was performed by 3 additional authors (FMA, HF, and ML) to make sure the reasons for extraction and retreatment were accurately recorded. As multiple factors can contribute to a decision to extract or retreat the root-filled tooth, an assessment of the most evident reason was made. In cases of disagreement, the information in the dental record was discussed until consensus was reached.

Events and Non-events

In the follow-up, cases with a tooth that had an additional treatment (ie, a terminal event, which is defined as an unsuccessful case) and cases with a tooth that did not require an additional event (ie, a nonterminal event) were identified. In both groups, the time for all individuals from the inclusion (ie, the RCT) to the end of the observation was determined. The analysis considered both terminal events and nonterminal events. In survival analysis, the latter group is denoted as "censored."

First additional treatments indicative of failure of the RCT for the tooth in question included orthograde root canal retreatment, endodontic surgery, and extractions or root amputations (ie, terminal events). Endodontic surgery, extractions, and root amputations were exclusively due to endodontic reasons (eg, pain, swelling, clinical signs of infection without evidence of vertical root fractures, and no radiographical healing). Fractures in the root or crown were not considered to be an endodontic reason. The registered date of the first additional treatment was considered a terminal event for that tooth.

Extractions and root amputations due to problems not related to endodontic reasons (eg, periodontal disease, vertical fractures, caries, in conjunction to prosthetic treatment, and including unknown reasons for extraction) were marked as nonterminal events. Teeth not subjected to an extraction were marked as nonterminal event until the last date of known existence in the mouth. This was performed almost exclusively by assessing clinical and radiographical material such as a radiograph where the tooth could be seen or notes indicating a restoration on the particular tooth.

Observation Period (Follow-Up)

The observation period started at the date of the completion of the RCT in 2006 and lasted until the date of the terminal event or if no terminal event was registered, the observation period lasted until teeth were marked as nonterminal event until the last date of known existence, as described above. Examples of observation periods of cases with terminal events and nonterminal events are shown in Figure 2.

Assessments and Calibration

All dental records were assessed by one researcher (SK). The researcher was calibrated with another researcher (FMA) during 2 different periods of the collection phase. The procedure and the high inter- and intraobserver agreements (over 90%) have been described and reported in the previously published article[4].

Statistical Analysis, Reporting, and Ethics

As this study is based on data collected for other purposes, no calculation of the required sample size was made. Missing data were left as such. No individual was excluded from the main analysis. Descriptive statistics were used to chart the additional treatments.

Data were analyzed with common methods for survival analysis: Kaplan–Meier plots and survival tables. SPSS Statistics, version 27 (IBM, Armonk, USA) was used. Univariate Cox regression models were used to analyze relationships of possible prognostic factors, with $P < .05$. A sensitivity analysis censoring all data at 10 years was performed. Due to the limited number of events, building regression models with more variables was not feasible.

The reporting of the present study complies with the STROBE statement[16]. The study was approved by the Regional Ethical Board at Umeå University, Sweden (ref: 2016-141-31M). The research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version 2008), and Swedish law.

RESULTS

The mean age of the 280 individuals was 45.2 years (range: 10–80, standard deviation: 15.16) and 140 were women (50%). More than half of the included teeth (52%) were molars. At baseline, 222 teeth were primary RCT, 8 were

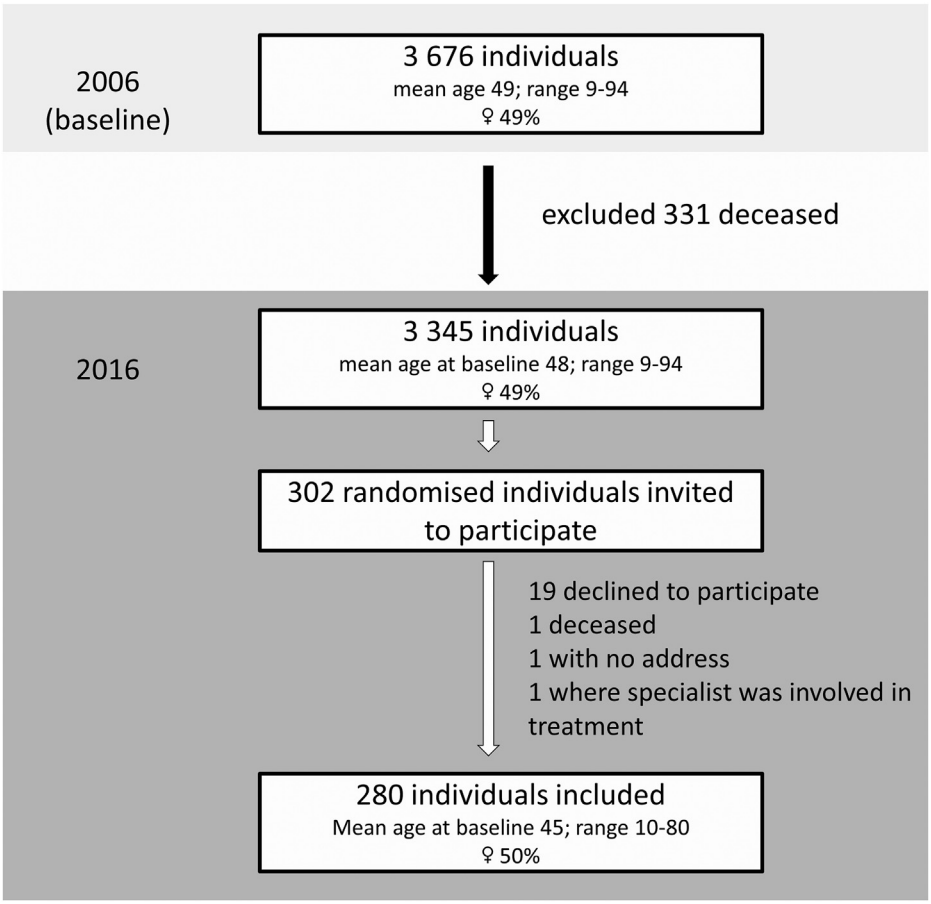

FIGURE 1 – Flow chart of included and excluded individuals from the total cohort of individual receiving a root canal treatment performed by general dental practitioners in North Bothnia during 2006. Reproduced from Kebke et al[4] with the permission of the publisher, John Wiley and Sons.

orthograde retreatment, and 50 teeth had missing information on whether they were root-filled or not at baseline.

All 280 individuals provided information to the survival analysis but not completely throughout the whole observation period as explained in Figure 2. Information on whether the orthograde RCT performed in 2006 had survived or failed at 3467 days (9.5 years) was available for 175 individuals (62.5%). During the observation period, 36 more teeth were extracted for nonendodontic reasons (12.9%).

For all included individuals ($n = 280$), there was no missing information on age, sex, tooth-type, date for orthograde RCT in 2006 (ie, the start of the observation period), or date for any terminal or nonterminal events.

Descriptive Analysis

During the observation period (range: 0–4373 days), 22 additional treatments (of which 15 in molars) were reported (Supplemental Table S1). There were 17 orthograde root canal retreatments (77%), 1 root amputation (5%), 4 extractions for endodontic reasons (18%), and no endodontic surgery (0%). In all orthograde retreatments but one (94%), treatment was initiated because of symptoms in the root-filled tooth.

Kaplan–Meier Curve

Figure 3 shows the Kaplan–Meier curve for survival until additional treatments, and Table 2 shows the life tables of the percentages of the cumulative incidence of additional treatments. After 3,650 days (10 years), which had a total of 18 terminal events, the cumulative survival was 92.7% (standard error [SE], 1.7%). The terminal event rate was not homogenous through time as the rate of additional treatments was steeper in the first 2 years (mean incidence of 2.7%) than in the last 8 years (mean incidence of 0.2%) (Fig. 3 and Table 2).

Univariate Regression Analysis

In the univariate regression analysis, 5 variables were statistically significant ($P < .05$). For individuals receiving care for up to 4 weeks with postoperative pain after completion of RCT, the risk increased compared with individuals who did not receive help (hazard ratio [HR]: 14.6, [95% confidence interval (CI): 4.44–47.72]; $P < .05$). If the root filling quality was judged to be inadequate (ie, not finishing 0–2 mm from radiographic apex, or with apparent voids), the risk increased compared to when it was considered adequate (HR: 5.94, [95% CI: 1.63–21.59]; $P < .05$). For each additional day elapsed between access preparation and root filling, the risk for a terminal event decreased (HR: 0.99, [95% CI 0.97–0.99]; $P < .05$). The risk increased slightly for each additional day elapsed between completed treatment and first coronal restoration (HR: 1.00, [95% CI: 1.00–1.01]; $P < .05$). Individuals with 2 or more nonelective emergency appointments at start and during RCT increased the risk for terminal events compared with those receiving at maximum one treatment (HR: 3.56, [95% CI: 1.00–12.64]; $P = .05$)

TABLE 1 - Variables Harvested From Dental Records and Radiographs From Individuals Who had a Tooth Root Filled by a GDP in the Year 2006 and Then Followed for up to 10 Years

Individual-related factors	Preoperative factors	Intraoperative factors	Postoperative factors
Age—reported in 2006 (y old)	Tooth type (molars, non-molars)	Prescription of antibiotics—reported use of (no, yes)	Postoperative pain—receiving care for up to 4 wk (no, yes)
Sex (male; female)	Number of proximal contacts—assessed by radiographs at baseline, or after if assessment could reflect the situation at baseline (0, more than 0)	Intrapulpal anesthesia—reported upon access (no, yes)	Extent of first permanent restoration after completed RCT—partial coverage with direct filling, or full coverage—direct or indirect, independent if it is a new construction or an old one maintained after RCT (partial coverage, full coverage)
Health status, reporting of diabetes, immunosuppressive medications or immunosuppressive medical conditions, or heart conditions (healthy, not healthy)	Terminal arch location—assessed by radiographs (no, yes)	Emergency appointments—number of nonelective appointments due to individuals' perceived acute problems at start and during RCT (once or less, twice or more)	Elapsed time between completed RCT and first restoration (d)
	Presence of sinus tract—reported or radiographic signs of tracing sinus tract (no, yes)	Number of caregivers—number of caregivers involved from access to completion of RCT (1, 2, or more)	Plug in the orifice of the root canal coronal to the root filling (no, yes)
	Apical status—contours and width of the periodontal ligament assessed by radiographs (normal, abnormal)	Number of sessions—to complete RCT (less than 5, more than 5)	Post—reporting or radiographic signs of placement of post after completed RCT (no, yes)
	Previous root filling—signs of presence of any filling material in pulp space before treatment reported or assessed by radiographs (signs, no signs)	Elapsed time between access preparation and root filling (d)	Abutment—tooth used as an abutment for fixed or removable prosthesis after completed RCT (no, yes)
	Marginal bone level—estimation of location of bone level in relation to root length assessed by radiographs (cervical 2/3. apical 2/3)	Rubber dam—evidence of use of rubber dam; ie, clamp seen in radiograph or notation in journal (no, yes)	
		Pulp bleeding—reporting of bleeding pulp in all canals upon access (no, yes)	
		Pulp necrosis—reporting pulp necrosis in at least one canal upon access (no, yes)	
		Apical size—reporting maximal apical size preparation in smallest canal (ISO)	
		Type of root canal filling—reporting use of gutta percha in combination with (sealer, rosin-chloroform)	
		Root filling quality—assessed adequate on radiograph if length to approximately 0–2 mm from apex and no voids (adequate, not adequate)	
		Procedural accidents—assessed on radiographs or reported filed fractures or iatrogenic perforations (no, yes)	

RCT, root canal treatment; GDP, general dental practitioner.

(Supplemental Table S2). Data on missing variables are shown in Supplemental Table S2. The sensitivity analysis revealed the same potential predictors ($P < .05$) with the exception of emergency appointments ($P = .192$).

DISCUSSION

This study of a historical cohort of individuals with orthograde RCTs performed by general

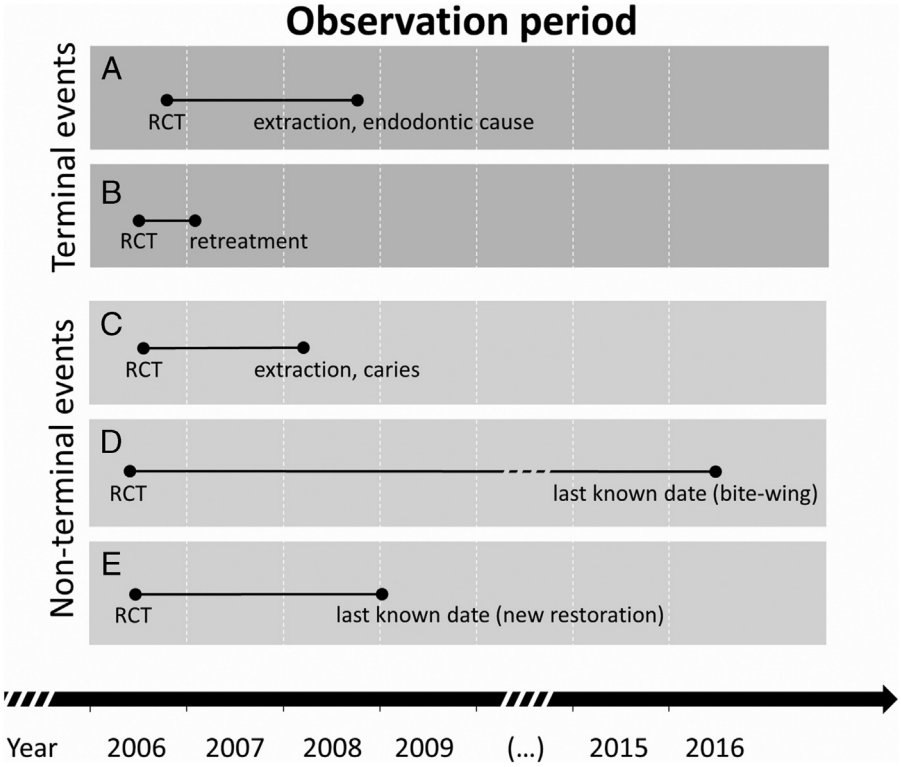

FIGURE 2 – Imaginary examples of how teeth (cases *A*–*E*) were followed over time reflecting the material and method in the present study. The teeth were followed from when the root canal treatment (RCT) was performed in 2006 until the occurrence of the first terminal events (ie, unsuccessful cases–extractions due to endodontic reasons as in case *A* or endodontic retreatments as in case *B*). When no terminal event occurred during the follow-up, the teeth were followed until an extraction due to nonendodontic reasons (as in case *C*, extracted due to caries) or until the last known date of existence of the tooth (cases *D* and *E*). In cases *D* and *E*, the individuals could not be followed in the records until the end of the 10-year follow-up. For case *D*, the tooth in question was seen in a bite-wing, confirming the survival of the tooth. For case *E*, the equivalent confirmation of survival of the tooth was due to a notation of the tooth receiving a new restoration. The time elapsed from performing the RCT in 2006 until the date of the terminal or nonterminal event (the length of the horizontal bar) for each case (*A*–*E*) was used for the survival analysis for all included cases. RCT, root canal treatment.

dentists calculated the incidence of a first additional treatment indicative of an unfavorable endodontic outcome during a 10-year period. The cumulative 10-year survival of orthograde RCTs was almost 93%. This rather high percentage is attributed to the somewhat unusual disregard of extractions performed for reasons other than endodontic.

The strengths and weaknesses of the methodology used in this study design are related to its retrospective nature and using the clinical registries of a heterogeneous group of GDPs, which were of varying degree of completeness, quality, and the reports naturally uncalibrated. However, specific issues concerning the present study are relevant.

A strength of the study is its adequate observation time for a good proportion of individuals; 75% of individuals had known extractions or confirmed surviving teeth after 9.5 years.

A unique feature of this study on RCT survival was the discrimination of reasons for extraction, only including extracted teeth due to endodontic reasons in the analyses. It is a step further to better understand RCT and when and why it fails using an outcome readily understood by patients. If the objective is to identify the factors that might enhance the outcome of RCT and predict its prognosis, it is probably undesirable to associate, for example, intraoperative variables of RCT such as type of sealer or pulp necrosis with outcomes such as indiscriminate extractions when they are largely due to caries or for reasons other than endodontic infections. That is, it is inaccurate to consider all these extractions a result of unfavorable outcome of the RCT as most of these extractions were not the result of endodontic infections or problems[4-10]. This approach risks diluting probable associations. To circumvent these problems, this study analyses only extractions that were endodontic related and teeth that received additional endodontic treatments. On the other hand, clinicians performing RCT should not neglect other factors associated with extractions, which may greatly affect the overall result.

A crucial aspect of the study is how confident the authors could be on the reason of the terminal events, especially extractions. As extracted teeth often have different pathologies synchronically, one could argue that the study results have some degree of ambiguity. To mitigate this aspect as much as possible, the researchers once more reviewed all extractions and retreatments. Moreover, when the authors disagreed, each case was discussed until consensus was established.

It could be argued that extractions as a consequence to vertical fractures (n = 13) could be interpreted as an unfavorable outcome due to endodontic reasons. This study does not include these teeth as a terminal event of interest but rather as another reason for extraction rather than classifying them as unsuccessful. This approach is debatable, however. Vertical fracture could have been the main reason for the endodontic pathology that justified the initial RCT. An unadjusted analysis showed that if fractures were included as an endodontic reason for extraction, the survival curve would be overall

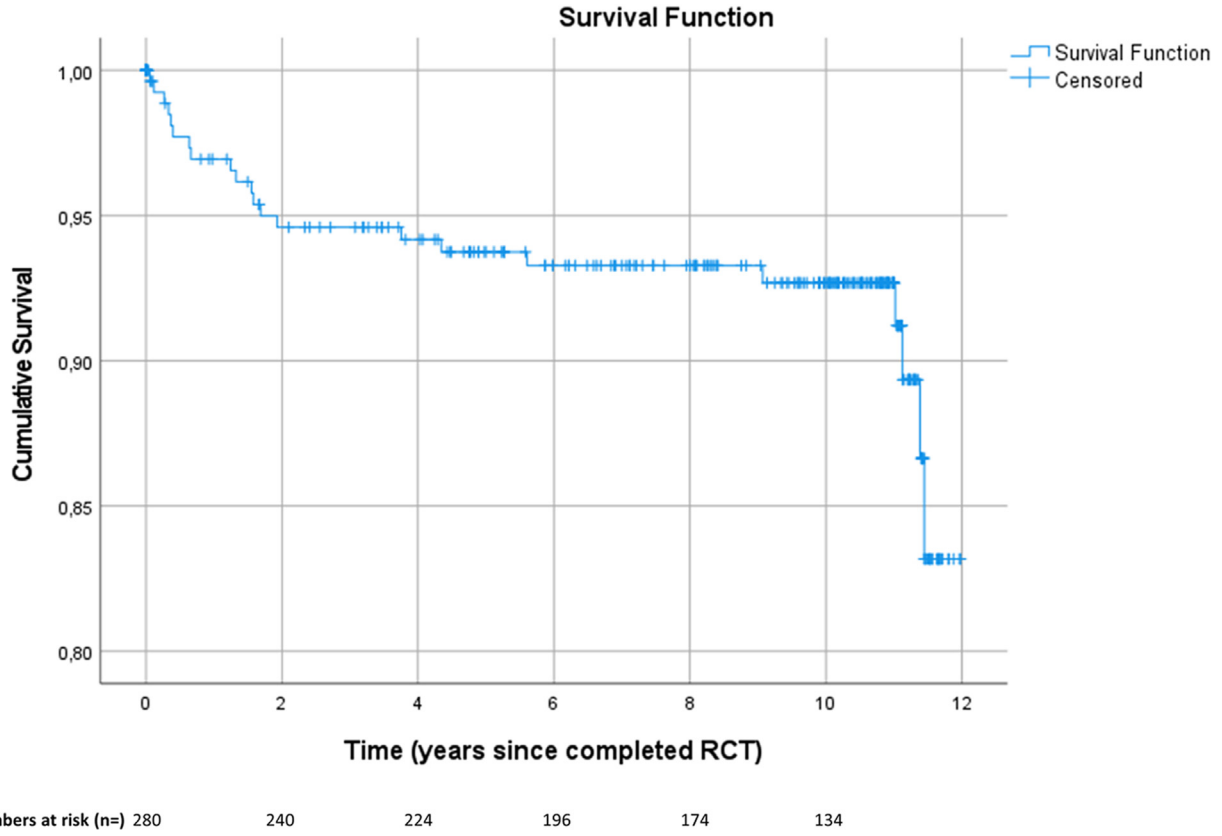

FIGURE 3 – Kaplan–Meier graph of survival of root canal treatment–that is, until the first registration of any of the terminal events (orthograde root canal retreatments, surgical endodontics, and tooth extractions exclusively due to endodontic reasons). RCT, root canal treatment.

steeper and more linear throughout the period, with a cumulative proportion of unfavorable outcome of 12.8% (SE: 2.2%) after 10 years (Supplemental Fig. S1).

The authors chose to censor extractions due to nonendodontic reasons in the Kaplan–Meier survival analysis. Therefore, these extracted teeth were less correctly treated the same as individuals not showing up at the clinic and providing evidence of the tooth being present in the mouth. For the latter individuals, the risk of experiencing the terminal event of interest is more correctly assumed to be the same as for the rest of the population[17]. Another approach could have been to treat the nonendodontic extractions as competing risks. This approach using competing risks analysis was used (data not shown). As both approaches had a very similar cumulative incidence, the simpler method without competing risks was chosen. This similarity was presumably because the events were relatively rare and nonendodontic extractions were of the same magnitude as the terminal events used in this study.

The results are regarded to have a high degree of external validity. The assessment is based on the use of a randomized sample of a larger cohort of thousands of consecutive individuals who had received an orthograde RCT in the public county council clinics in a Swedish county in 2006. The county council clinics accounted for a vast majority of RCTs reported in 2006 in the county. Almost none of the individuals from the randomized sample declined to participate. The present sample probably represents larger populations as the previously reported nonspecific tooth survival results were very similar to a large registry study that included practically the whole Swedish population[3,4].

Another strength of the study was recalling individuals whose records had missing data on the outcome, a strategy that improved the accuracy of the data. In addition, the authors could report known outcomes for very long follow-ups for a high proportion of individuals, an uncommon approach in retrospective endodontic studies.

The study was undersized to study predictors for unfavorable outcomes, which was the secondary aim; it included 280 individuals with a rather low proportion of terminal events. With the number of terminal events in the present study, the cohort would have been needed to be more than twice its size to study 5 prognostic factors in a multivariable model.

The results showed a cumulative proportion of unfavorable outcome of orthograde RCT of 7.3% (SE: 1.7%) after 10 years, which is a better result compared to the overall, nonspecific, tooth survival for the same individuals[4]. The 5-year results are comparable to the reported results of a Taiwanese study[5] and should be comparable to a large Swedish registry study if extractions are assumed to be ascribed only in a minority of cases to endodontic pathology[14]. Interestingly, the present study reported a slightly higher occurrence of orthograde retreatments for the equivalent 5-year period compared to the other comprehensive study—4.6% versus 2.2%[14]. This difference could be due to regional variations as the adaption to the concept of functional retention probably varies across the country. Nevertheless, the present results indicated that orthograde retreatment, not extraction, tended to be the first option of treatment in general practice if

TABLE 2 - Life Table of Cumulative Survival of RCT–that is, Until First Registration of any of the Terminal Events (Orthograde Root Canal Retreatments, Surgical Endodontics, and Tooth Extractions Exclusively due to Endodontic Reasons). Time Indicates Years From Initial RCT

	Time (y)						
	1	2	4	5	6	8	10
Cumulative survival % (SE)	96.9 (1.1)	94.6 (1.4)	94.2 (1.5)	93.7 (1.5)	93.4 (1.6)	93.3 (1.6)	92.7 (1.7)

SE, standard error.

the treating GDP diagnosed the reason for symptoms to be endodontic. The results are supported by data from another study[5]. As other studies on survival do not distinguish between reasons for extraction, they are not fully comparable.

The data show that RCTs failed more frequently during the first 2 years after completion of the RCT and that the incidence of unfavorable outcome decreased over the next 8 years. In the radiographic healing assessment of apical health, healing occurs for the vast majority of teeth during the first 2 years[18]. Vire[10] calculated that on average 20.6 months passes between the time of an endodontic treatment and tooth extraction as the result of unfavorable endodontic outcome. In a 5-year follow-up study of 858 teeth, Chen reported that 15 of 24 retreated teeth (orthograde and surgical) were intervened during the first 2 years after treatment[5]. The first 2 years after treatment seem to be important for endodontic events, most notably symptomatic events, even if some teeth can be affected by later events. The events are too few to understand whether the composite of different events classified as terminal could explain the curve behavior. A larger study population could permit a more partitioned analysis and shed some more light to this finding.

Surgical treatments performed shortly after initial RCT may not be a sign of an unfavorable endodontic outcome but part of an initial treatment plan, merely reflecting a more complex clinical situation. These more complex treatment plans may be more common in specialist practices. In the present cohort, which only included RCTs performed by GDPs, no teeth were subjected to endodontic surgery. The only root amputation was performed acutely to resolve a localized abscess and consequently was interpreted as a failing initial RCT.

In the present study, orthograde retreatments as well as extractions for endodontic reasons were almost entirely performed to treat symptomatic teeth. It is common for apical periodontitis to be asymptomatic, although the primary indication of RCT in general public practice is relief of symptoms[19]. Endodontically treated teeth have persistent symptoms only in a small proportion of individuals. Moreover, when present, the symptoms are generally mild and have little impact on daily life[20]. It is reasonable to assume that symptoms, especially intense symptoms, are the main reasons people seek help and initiate a first RCT; this is also true for additional endodontic treatment although additional endodontic treatments seem less common in nonspecialist settings[19]. It is worth noting that the region of North Bothnia is a rural region with chronic dental personnel shortages; one endodontic specialist serves around 250,000 people. However, it is not clear that the reasons and timing for further treatment would be transferrable to smaller private clinics, with a known and loyal clientele where healing controls may be performed. Under such circumstances, treatments could potentially be initiated by asymptomatic radiographically enlarging lesions or nonhealing lesions after a given time.

From a biological point of view, asymptomatic apical periodontitis is considered an unfavorable outcome[21]. In the present material, with a follow-up of 10 years, some teeth would most probably have an apical radiolucency and should be judged as a biologically failing RCT. In a Swedish cross-section study, the prevalence of apical periodontitis in root-filled teeth was 30%[22]. Although this study does not investigate apical health, it is reasonable to assume that around the same proportion of surviving root-filled teeth had apical periodontitis. The health consequences of not treating root-filled teeth that have apical periodontitis is largely unknown[23,24].

The small proportion of additional treatments of teeth with asymptomatic apical periodontitis (ie, leaving root-filled teeth with radiographic signs of disease without any intervention) is an interesting finding. However, explaining why this is the case is only a speculation as it is not known whether this is due to patients' or dentists' preferences, or simply a result of underdiagnoses. The reasons for not treating these teeth could be better explored with a qualitative approach, which could delve deeper into the subject.

The curve behaved differently after 10 years. This might be due to less numbers at risk and higher uncertainty, or that long-term events might potentially be different. No change in pattern of the terminal events could be observed, but the events are too few to conclude anything (Supplemental Table S2). A sensitivity analysis with data censored at 10 years was performed with no major differences in regard to predictors. In summary, additional treatments indicative of an unfavorable outcome of the RCT (ie, retreatments and extractions due to only endodontic reasons) performed by GDPs are driven mostly by symptoms. For root-filled teeth with additional treatment, orthograde retreatment was more common than extraction. The mean yearly incidence of unfavorable RCT outcome was less than 1% when root-filled teeth were followed for 10 years, with a cumulative survival of 92.7% (SE 1.7%). The gradient was not linear as it was markedly steeper during the first 2 years. In the univariate analysis, 5 indicators were associated with the outcome: (1) postoperative pain, (2) root filling quality, (3) elapsed time between access preparation and root filling, (4) elapsed time between completed RCT and first restoration, and (5) emergency appointments. However, confounders could not be excluded from the associations. As the results are based on a few events, they should be judged cautiously. Studies, preferably of prospective studies, with larger populations and longer follow-ups are needed.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Fernando José Mota de Almeida: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft. **Robert Lundqvist:** Conceptualization, Formal analysis, Writing – review & editing. **Stephen Kebke:** Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Validation, Writing – review & editing. **Helena Fransson:** Conceptualization, Writing – review & editing. **Malin Brundin:** Conceptualization, Supervision, Writing – review & editing.

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SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2022.12.011).

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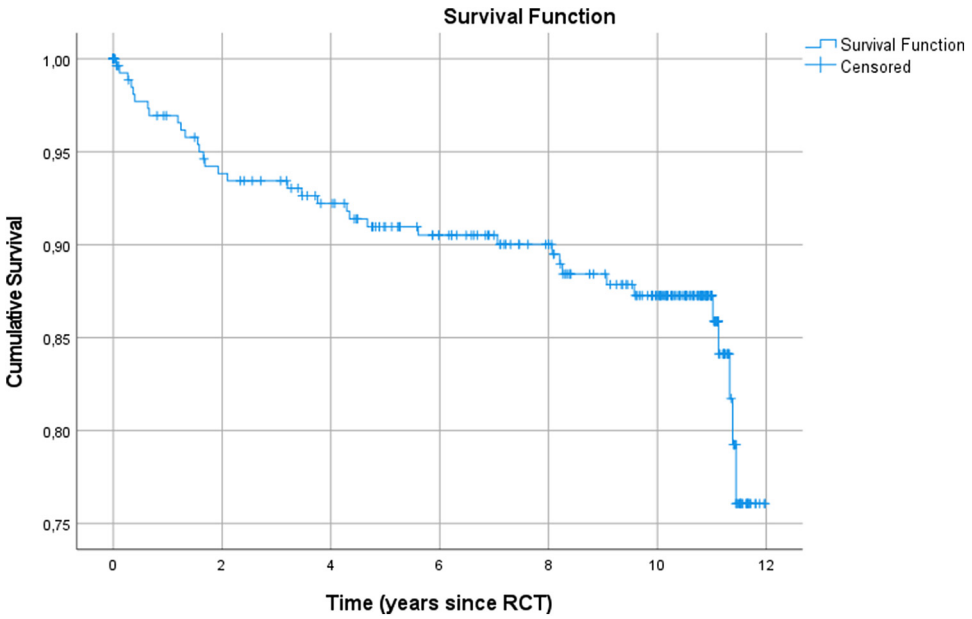
SUPPLEMENTARY MATERIAL



SUPPLEMENTAL FIGURE S1 – Kaplan–Meier graph of survival of root canal treatment including extractions due to vertical root fractures as an indication of failure–that is, until the first registration of any of the terminal events (orthograde root canal retreatments, surgical endodontics, tooth extractions exclusively due to endodontic reasons and vertical root fractures).

SUPPLEMENTAL TABLE S1 - Information of all cases with terminal events (root canal retreatments, root amputations, and extractions due to endodontic pathology), that is, the additional treatments indicative of an unfavorable endodontic outcome

First additional treatment	Case	Age (y) sex	Tooth	Clinical and radiological status *(diagnosis)**	Elapsed time since completion of first treatment in days (years, months)
Root canal retreatment	#1	42 M	3	Symptoms after initial treatment	21 (0 y, 0 m)
	#2	21 M	30	Discomfort 1 mo after initial treatment, apical radiolucency *(Symptomatic Apical Periodontitis)*	43 (0 y, 1 m)
	#3	66 F	14	Pain, no apical radiolucency *(Symptomatic Apical Periodontitis)*	98 (0 y, 3 m)
	#4	50 M	19	Continued discomfort after initial treatment, no apical radiolucency *(Unclear Diagnosis)*	121 (0 y, 3 m)
	#5	56 M	31	Pain, severe tenderness, in individual suffering from chronic neuralgic pain after accident, slightly widened periodontal space (*Unclear Diagnosis*)	133 (0 y, 4 m)
	#6	66 M	8	Continued discomfort after initial treatment, no apical radiolucency *(Unclear Diagnosis)*	145 (0 y, 4 m)
	#7	46 F	6	Tenderness *(Unclear Diagnosis)*	233 (0 y, 7 m)
	#8	71 F	30	Swelling, apical radiolucency *(Acute Apical Abscess)*	454 (1 y, 2 m)
	#9	58 M	9	Severe discomfort/pain	567 (1 y, 6 m)
	#10	55 M	14	Swelling, apical radiolucency *(Acute Apical Abscess)*	615 (1 y, 8 m)
	#11	10 M	9	No symptoms recorded, small apical radiolucency *(Asymptomatic Apical Periodontitis)*	704 (1 y, 11 m)
	#12	25 F	14	Discomfort, tender, and widened periodontal space *(Symptomatic Apical Periodontitis)*	1,371 (3 y 9 m)
	#13	38 M	14	Swelling, apical radiolucency *(Acute Apical Abscess)*	1,585 (4 y, 4 m)
	#14	22 F	4	Slight symptom, apical radiolucency, and planning crown therapy	3,311 (9 y, 0 m)
	#15	24 F	20	Pain, apical radiolucency 35, light tender to percussion	4,061 (11 y, 1 m)
	#16	46 M	30	Pain, apical radiolucency *(Symptomatic Apical Periodontitis)*	4155 (11 y, 4 m)
	#17	19 F	19	Pain, apical radiolucency *(Symptomatic Apical Periodontitis)*	4,178 (11 y, 5 m)
Root amputation	#18	41 F	14	Acute *(Acute Apical Abscess)*	241 (0 y, 7 m)
Extraction due to endodontic pathology	#19	79 M	19	Acute, pain, apical radiolucency *(Symptomatic Apical Periodontitis)*	484 (1 y, 3 m)
	#20	42 M	14	Sinus tract, apical radiolucency *(Chronic Apical Abscess)*	578 (1 y, 7 m)
	#21	32 M	30	Acute severe symptoms, pain, apical radiolucency *(Symptomatic Apical Periodontitis)*	2,046 (5 y, 7 m)
	#22	35 F	4	Sinus tract (resorption in the middle of root), juxta-radicular radiolucency *(Chronic Apical Abscess)*	4,022 (11 y, 0 m)

F, female; M, male.

*The diagnosis is based on information from the dental record; either the directly stated diagnosis or when enough information permitted inference by the authors using the AAE classification; *Unclear Diagnosis* if this was not possible.

SUPPLEMENTAL TABLE S2 - Frequencies of various variables harvested from dental records and radiographs, respective numbers of additional treatments (AT) as defined in text, and hazard ratios calculated in univariate Cox regression models

Variable		Frequencies and means when appropriate (*n*, means when appropriate)	AET *n* (% of cases)	Cox regression univariate analysis Hazard ratio (95% CI)	*P* Value
Individual-related factors					
Age	Y	mean 45.28 ($n = 280$)	22 (7.9)	0.989 (0.964–1.015)	.41
Sex	Male (0)	140	13 (9.3)	0.675 (0.288–1.580)	.36
	Female (1)	140	9 (6.4)		
	Missing	0	0 (0)		
Disease	Healthy (0)	242	19 (7.9)	2.031 (0.589–7.000)	.26
	Not healthy (1)	23	3 (13.0)		
	Missing	15	0 (0)		
Pre-operative factors					
Tooth type	Non-molars (0)	135	7 (5.2)	2.119 (0.862–5.207)	.10
	Molars (1)	145	15 (10.3)		
	Missing	0	0 (0)		
Number of contact points	0 (0)	7	1 (14.3)	0.508 (0.068–3.822)	.51
	more than 0 (1)	237	17 (7.2)		
	Missing	36	4 (11)		
Terminal arch location	No (0)	228	18 (7.9)	0.439 (0.059–3.287)	.42
	Yes (1)	27	1 (3.7)		
	Missing	25	3 (12.0)		
Presence of sinus tract	No (0)	199	15 (7.6)	0.627 (0.083–4.767)	.65
	Yes (1)	23	1 (4.3)		
	Missing	58	6 (10.3)		
Apical status	Normal status (0)	61	3 (4.9)	1.940 (0.485–7.770)	.35
	Abnormal status (1)	69	6 (8.7)		
	Missing	150	13 (8.7)		
Previous root filling	No (0)	222	15 (6.8)	2.500 (0.327–19.131)	.38
	Yes (1)	8	1 (12.5)		
	Missing	50	6 (12.0)		
Marginal status	Cervical 2/3 (0)	230	20 (8.7)	0.046 (0.000–419.779)	.51
	Apical 2/3 (1)	11	0 (0)		
	Missing	39	2 (5.1)		
Intraoperative factors					
Antibiotics	No (0)	173	9 (5.2)	2.497 (0.886–7.039)	.08
	Yes (1)	44	6 (13.6)		
	Missing	63	7 (11.1)		
Intra-pulpal anaesthesia	No (0)	208	13 (6.2)	0.048 (0.000–1,514,134)	.70
	Yes (1)	5	0 (0)		
	Missing	67	9 (13.4)		
Emergency appointments	Once or less (0)	203	12 (5.9)	3.560 (1.003–12.642)	.05*
	Twice or more (1)	15	3 (20.0)		
	Missing	92	7 (7.6)		
Caregivers	One (0)	159	9 (5.7)	1.595 (0.592–4.296)	.36
	Two or more (1)	73	7 (9.6)		
	Missing	48	6 (12.5)		
Number of sessions	Less than five (0)	202	14 (6.9)	0.960 (0.218–4.228)	.96
	More than five (1)	31	2 (6.5)		
	Missing	47	6 (12.8)		
Elapsed time between access preparation and root filling	D	mean 118 ($n = 204$)	14 (6.9)	0.986 (0.972–0.999) for each additional day	<.05*
	Missing	76	8 (10.5)		
Rubber dam	No (0)	19	1 (5.2)	0.935 (0.116–7.546)	.95
	Yes (1)	109	8 (7.3)		
	Missing	152	13 (8.6)		
Pulp bleeding	No (0)	177	12 (6.8)	1.524 (0.428–5.426)	.51
	Yes (1)	33	3 (9.1)		
	Missing	70	7 (10.0)		
Pulp necrosis	No (0)	130	9 (6.9)	1.062 (0.378–2.986)	.91
	Yes (1)	80	6 (7.5)		
	Missing	70	7 (10.0)		
Apical size	(ISO)	208 (range #10–80)	12 (5.7)	1.005 (0.967–1.043)	.81
	Missing	72	10 (13.9)		

(*continued on next page*)

SUPPLEMENTAL TABLE S2 - Continued

Variable		Frequencies and means when appropriate (*n*, means when appropriate)	AET *n* (% of cases)	Cox regression univariate analysis Hazard ratio (95% CI)	*P* Value
Type of root canal filling	Sealer (0)	152	9 (5.9)	1.566 (0.583–4.208)	.37
	Rosin-chloroform (1)	77	7 (9.1)		
	Missing	51	6 (11.8)		
Root filling quality	Adequate (0)	116	3 (2.6)	5.938 (1.633–21.594)	<.05*
	Not adequate (1)	69	10 (14.5)		
	Missing	95	9 (9.5)		
Procedural accidents	No (0)	170	15 (7.6)	0.048 (0.000–643,754)	.72
	Yes (1)	4	0 (0)		
	Missing	106	7 (6.6)		
Post-operative factors					
Post-operative pain	No (0)	222	14 (6.3)	14.565 (4.445-47.725)	<.05*
	Yes (1)	8	4 (50.0)		
	Missing	50	4 (8.0)		
Extent of first permanent restoration after completed RCT	Partial coverage (0)	171	11 (6.4)	1.978 (0.818–9.779)	.13
	Full coverage (1)	77	9 (11.7)		
	Missing	32	2 (6.2)		
Elapsed time between completed RCT and first restoration	D	mean 34.084 $n = 277$ ($n = 15$ censored cases before earliest event in a stratum)	22 (7.9)	1.003 (1.000–1.007) for each additional day	<.05*
	Missing	3	0 (0)		
Plug in the orifice of the root canal coronal to the root filling	No (0)	164	10 (6.1)	1.742 (0.740–4.102)	.20
	Yes (1)	105	11 (10.5)		
	Missing	11	1 (9.1)		
Post	No (0)	211	18 (8.5)	0.406 (0.094–1.750)	.23
	Yes (1)	52	2 (7.9)		
	Missing	17	2 (11.8)		
Abutment [tooth used as an abutment for fixed ($n = 2$) or removable prosthesis ($n = 4$)]	No (0)	253	22 (8.7)	0.048 (0.000–39,682)	.66
	Yes (1)	6	0 (0)		
	Missing	21	0 (0)		

AET, additional endodontic treatments; RCT, root canal treatment; 95% CI, 95% confidence interval; SD, standard deviation.
*$P < .05$. Hazard ratio is calculated using the group designated as 0 as the reference group.