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Further treatments of non-surgically root canal-treated teeth in public dental service: A long-term register-based study

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ABSTRACT

Objectives: Our objective was to assess further restorative treatments, extractions and endodontic retreatments registered for root canal-treated teeth (RCTT) in a 13- to 15-year follow-up at Public Dental Service (PDS), and to examine the association of the frequency of further treatments with patient-, tooth-, and operator-related factors.

Methods: Data were collected from electronic patient records of the Helsinki PDS. Based on dental treatment codes, teeth with registered primary non-surgical root canal treatments (nsRCTs) (n = 16 954) between 2002 and 2004 were followed until the end of 2016. Estimation of incidence of further treatments was calculated with generalized linear model. Cox regression model was conducted to estimate the influence of patient-, tooth- and operator-related factors of the primary nsRCT for further restorative treatments, extractions, or endodontic retreatments.

Results: Further restorative treatments were the most often carried out treatments (38.2%) for RCTT, followed by extractions (19.5%), non-surgical retreatments (4.8%) and surgical retreatments (0.5%). Endodontic retreatments were often registered within few years of the primary nsRCT while the frequency of extractions remained nearly constant over the years. Younger age, anterior teeth, and teeth with indirect coronal restorations were mostly associated with lower incidence of further treatments.

Conclusion: Our study demonstrated that RCTT were registered with mainly further restorative treatments after primary nsRCT. One-fifth of teeth were extracted during the study period, while endodontic retreatments were uncommon. Placement of indirect restoration was associated with lower incidence of further treatments, within the limitations of this study.

Clinical significance: Knowledge of further treatments that root canal-treated teeth may require is highly important for both dentists and patients. Identification of risk factors that could have influence on further treatments after primary non-surgical root canal treatment should be part of the treatment planning to ensure favorable outcomes.

1. Introduction

Non-surgical root canal treatment (nsRCT) is one of the cornerstones of modern dentistry, and often the ultimate treatment for tooth preservation. The main objective of nsRCT is to eliminate the presence of microbes and seal the root canal system with a root filling, ultimately protecting the tooth with a permanent coronal restoration [1]. The global prevalence of individuals with at least one root canal-treated tooth (RCTT) is over 50% [2]. Hence, the economical perspective of nsRCTs is significant as a Swedish study revealed that the mean cost per tooth with root filling and subsequent further treatments was approximately 1 000 euros over a 10- to 11-year follow-up [3]. In the same study, fees were found to be even higher for teeth extracted after nsRCT. Endodontic retreatments are rarely found in large patient cohorts and occur mostly in the first three years after primary nsRCT [4]. In addition, register-based and cohort studies have demonstrated that cumulative tooth survival after nsRCT can be a satisfactory 80% in the long-term [5–7]. Similarly, a Swedish register-based study found that 20% of RCTT were registered with an extraction in a follow-up period of 10–11 years, while endodontic retreatments were uncommon. Also, further

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direct restorations were done for over 40% of RCTT with initially placed direct restoration [8].

Different prognostic variables are often investigated in survival analysis although they could reveal interesting results with other outcomes such as further restorative treatments or endodontic retreatments [9,10]. For instance, Elmaasarawi et al. [11] reported that treatment protocol, patient age, and supporting periodontal treatments were indications for further treatments. Another study investigated whether immediate or delayed placement of direct restoration for RCTT influenced the incidence of endodontic retreatments or tooth survival but did not find any statistical link in a 5-year follow-up [12]. Some studies have focused on further treatments for direct or indirect restorations without an endodontical context, although these findings could be extrapolated to RCTT [13,14]. Nevertheless, one study found that RCTT with indirect restorations had less further treatments within five years of primary nsRCT than those with direct restorations [15]. In general, molar teeth and direct composite restorations are registered to have more further treatments than anterior teeth and indirect restorations [8,16].

There is limited literature investigating further treatments of RCTT at Public Dental Service (PDS). Previous studies have mainly assessed success or survival rates of RCTT. In the few studies investigating further treatments, the length of follow-ups has been shorter or the prognostic factors for further restorative treatments, extractions or endodontic retreatments have not been investigated thoroughly. The purpose of this register-based study was to follow RCTT at Helsinki PDS over a 13- to 15-year follow-up to determine the frequency of further restorative treatments, extractions, and endodontic retreatments. Additionally, a particular interest was set on whether patient-, tooth-, or operator-related factors influence the incidence of further treatments. The null hypothesis (H_0) was that the frequency of further restorative treatments, extractions and endodontic retreatments do not differ significantly, and that the impact of patient-, tooth-, or operator-related factors on further treatments do not differ significantly in explaining the incidence of further treatments.

2. Materials and methods

Data for this register-based study were collected from the electronic patient record system EFFICA (Tieto Oyj, Helsinki, Finland) used by the Helsinki PDS. Our study included completed primary nsRCTs performed between 2002 and 2004 on adults aged 18 years or more. Treatments on third molars or primary teeth were excluded. No radiographs or clinical parameters were assessed in this study. In total, 18 719 patients with 22 906 RCTT were found between the years 2002 and 2004. To reduce the risk of bias, we selected only one RCTT per individual by the earliest date of primary nsRCT (n = 16 954). Early failures, such as extractions, hemisections, radectomies or apical surgeries before registration of initial coronal restoration, were excluded. Only completed nsRCTs were

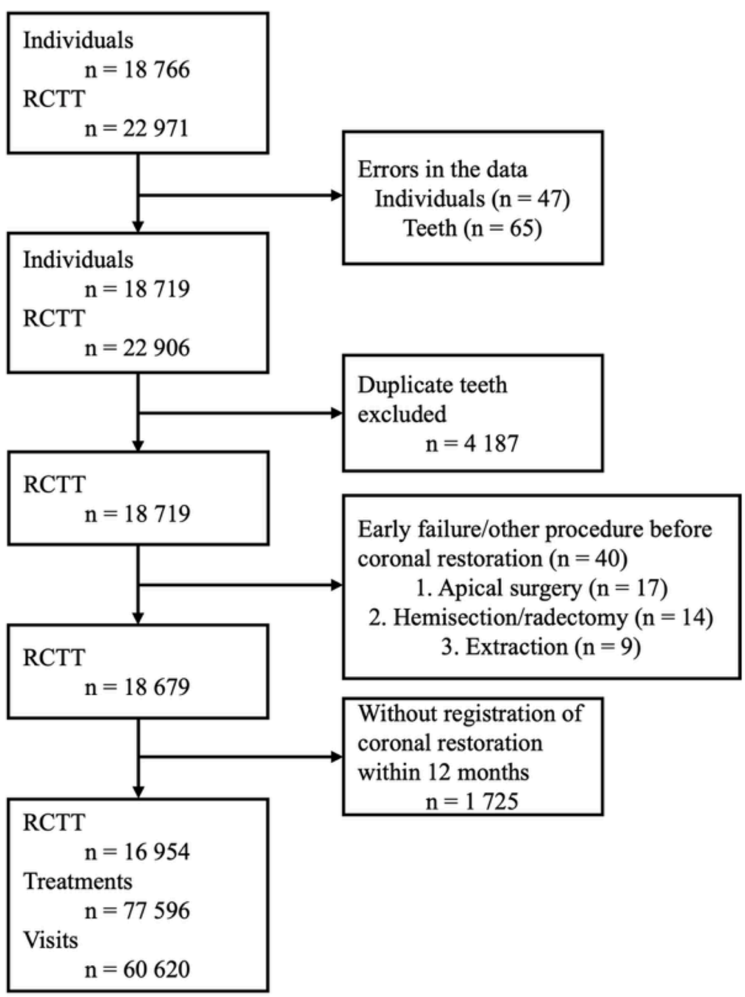


Fig. 1. Study subjects and non-surgically root canal-treated teeth included in the study.
Number of patients and teeth that received primary non-surgical root canal treatment between 2002 and 2004, and the total number of visits and treatments these teeth accumulated until the year 2016. Duplicate teeth signify that one patient had more than one RCTT during the study period. Treatment codes refer to as treatments provided, and visits refer to different time points.

included which is why teeth without any coronal restoration registered within 12 months of the root canal filling were excluded. The full selection process is illustrated in Fig. 1. After the primary nsRCT and initial coronal restoration, we determined which other treatments were registered on the same tooth: further restorative treatment, extraction and non-surgical or surgical endodontic retreatment. Due to the low number of hemisections and radectomies (n = 20), they were considered as extractions. Altogether, the included teeth received 77 596 treatments in 60 620 visits, spanning the period from the first root canal opening to the most recent observation. The mean number of treatments per tooth was 4.6.

Completed primary nsRCTs and further treatments were selected based on treatment codes registered by dentists. The codes are maintained by The National Institute for Health and Welfare (THL), see Appendix A. If nsRCT was performed on multiple visits, intracanal medication was placed between appointments. Patient-related characteristics included age and sex (man/woman). Age of the patient at the time of primary nsRCT was divided into four groups: 18–29 years, 30–49 years, 50–64 years, 65+ years. Tooth types were grouped as anterior, premolar, and molar. Coronal restoration was defined as the first restoration code found after primary nsRCT. Information on coronal restorations was available regarding their material and whether they were direct or indirect. Ceramics and gold restorations were referred to as indirect restorations, regardless of the material. Other materials (composite, amalgam, glass-ionomer cement (GIC), temporary) were placed as direct restorations. If direct restoration was replaced within one year of primary nsRCT by indirect restoration, the final type of restoration was referred to as indirect. Similarly, all temporary and GIC restorations were replaced by direct composite, amalgam, or indirect restorations if found within 12 months of primary nsRCT. Operator-related factors were public general dentist (GD), endodontist, dental student, and GD in purchased service, meaning private dentists from whom the City of Helsinki can purchase dental services.

2.1. Ethical considerations

This study was based on encrypted summary data of electronic health records. Individuals could not be identified, and therefore, ethical permission was not applicable. Permission for this study was granted by the City of Helsinki (Research permission HEL2022-013,077).

2.2. Statistical analyses

Statistical analyses were performed with IBM SPSS Statistics (version 31.0.0.0). Continuous variables were reported as means (M) with standard deviation (SD). Normal distribution of the variables was tested with Kolmogorov-Smirnov test. Categorical variables were compared with Chi-square or Fisher's exact test using Bonferroni correction as post-hoc test. Kruskal-Wallis test was used for comparison of median times of treatment categories following initial coronal restoration. We established a generalized linear model (GLM) following negative binomial distribution with log link function to determine which factors contributed to incidence of further treatments. Negative binomial distribution was used instead of Poisson distribution to adjust for overdispersion. Model fit was assessed with Goodness of Fit statistics which were as follows: deviance/degrees of freedom (df) = 0.968, Pearson Chi-square/df = 0.987, Likelihood Ratio Chi-square 328.502, and $p < 0.001$. All treatments after initial coronal restoration were included to provide incidence risk ratios (IRRs). Treatments were grouped as one regardless of how many visits they required. Estimated marginal means (EMMs) were given for selected variables. This can be interpreted as a model-based estimation for group mean. Hence, EMM will be referred to as the expected average number of further treatments.

Cox regression model was used to test which variables explained the propensity of RCTT for further restorative treatment, extraction, or non-surgical or surgical retreatment through hazard ratios (HRs). All of the variables were included in the model simultaneously. Proportional hazard assumption was assessed visually with log-minus-log plots. We set a statistically significant value at 0.05, and p-values under 0.001 were considered to be highly significant. Confidence interval (CI) of 95% was used.

3. Results

3.1. Description of the study population

At least one further treatment was registered for 48.7% of RCTT. At the time of root canal filling, the mean patient age was 40.4 years (SD 13.5) (Table 1). Of all RCTT, 51.9% belonged to women and 48.1% to men. Molars represented approximately half (50.9%) of all teeth. Over three-fourths of the nsRCTs were performed by public GDs. Direct composite restorations were dominant, accounting for 92.3% of all initial coronal restorations. Comparing by tooth types, indirect restorations were placed more often to molar teeth than anterior teeth ($p < 0.001$).

After placement of initial coronal restoration, mean number of further treatments for all teeth was 0.96 (SD 1.37). Of all 16 329 registered treatments, further direct restoration (67.5%) was the most common single procedure carried out for RCTT during the follow-up. Total frequencies and distribution of further treatments within teeth with at least one further treatment are shown in Table 2. We found some differences between age groups in the frequency of provided further treatments. For instance, non-surgical retreatments were rarely found when patients were aged 50 years or more, while extractions were more uncommon within the age category of 18–29 years.

Of all RCTT, 38.2% had further restorative treatment, 19.5% were extracted, 4.8% had non-surgical retreatment, and 0.5% had surgical retreatment. Frequency of further treatments at a specific time-point after initial coronal restoration is shown in Fig. 2. Median time for a treatment to occur after primary nsRCT was 6.51 years for extraction, 3.76 years for non-surgical root canal retreatment, 3.31 years for further restorative treatment, and 0.97 years for surgical retreatment, respectively. Median times of the four treatment categories differed statistically significantly ($p < 0.001$).

3.2. Incidence risk ratios of further treatments

Patient age, tooth type, sex, and type of coronal restoration were

Table 1
Baseline characteristics of the study population at the time of primary non-surgical root canal treatment.

	Women (n = 8800)	Men (n = 8154)
Mean age (SD)	40.5 (13.7)	40.3 (13.3)
Tooth type (%)		
Anterior	1276 (14.5)	1505 (18.5)
Premolar	3008 (34.2)	2535 (31.1)
Molar	4516 (51.3)	4114 (50.4)
Jaw (%)		
Maxilla	4823 (54.8)	4514 (55.4)
Mandible	3977 (45.2)	3640 (44.6)
Operator (%)		
Public GD	6937 (78.8)	6466 (79.3)
GD in PS*	1198 (13.6)	1150 (14.1)
Endodontist	385 (4.4)	333 (4.1)
Dental student	280 (3.2)	205 (2.5)
Coronal restoration after nsRCT (%).		
Composite	8222 (93.4)	7419 (91.0)
Amalgam	335 (3.8)	522 (6.4)
Indirect	72 (0.8)	46 (0.6)
GIC	127 (1.5)	140 (1.7)
Temporary	44 (0.5)	27 (0.3)

*PS = Purchased Service. Percentages show the frequency within women or men.

Table 2
Frequency of further treatments after initial coronal restoration of root canal-treated teeth by age groups.

	18–29 n (%)	30–49 n (%)	50–64 n (%)	65+ n (%)	All n (%)	P-value
Further treatments						**<0.001**
Restorative treatment	1047[a] (79.1)	6431[b] (74.5)	3161[c] (71.2)	1417[b,c] (73.1)	12 056 (73.8)	
Extraction	168[a] (12.7)	1637[b] (19.0)	1074[c] (24.2)	460[c] (23.7)	3339 (20.4)	
Non-surgical retreatment*	99[a] (7.5)	503[a] (5.8)	184[b] (4.1)	58[b] (3.0)	844 (5.2)	
Surgical retreatment[#]	10[a] (0.7)	56[a] (0.7)	21[a,b] (0.5)	3[b] (0.2)	90 (0.6)	
All	1324	8627	4440	1938	16 329	

Chi-square test with Bonferroni correction was performed. Groups with different letters [a,b or c] differ from each other with statistical significance of <0.05. *Root canal opening and root filling were grouped as one completed treatment. [#]Fisher's exact test.

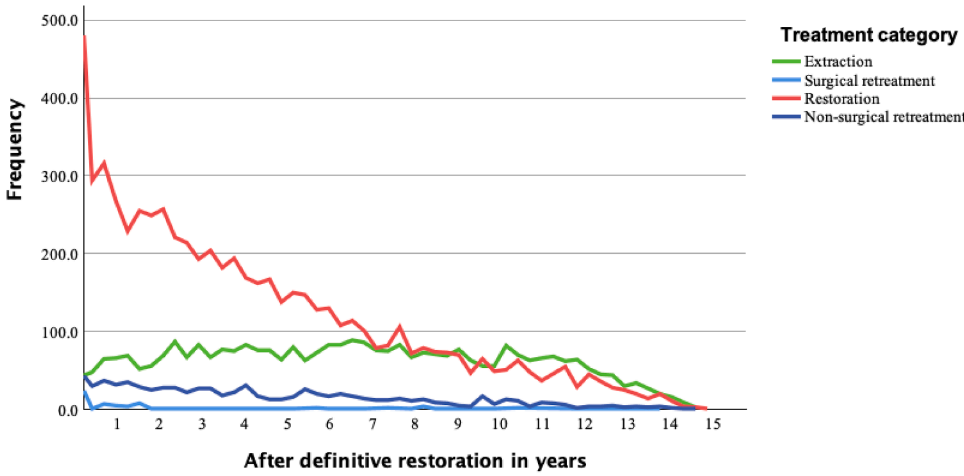


Fig. 2. Frequencies of further treatments after initial coronal restoration of root canal-treated teeth in a follow-up of 13- to 15-years.

statistically significantly associated with the overall incidence of further treatments. Incidence rates were higher for all other age groups than for the age group of 18–29 years. The highest incidence rate was found for the group of 65+ years (IRR 1.57, 95% CI 1.42–1.73, $p < 0.001$), indicating a 57% higher incidence of further treatment. In comparisons by tooth types, molars had a higher incidence of further treatments than anterior teeth (IRR 1.27, 95% CI 1.19–1.36, $p < 0.001$). Men were estimated to have 14% lower likelihood of further treatments than women (IRR 0.86, 95% CI 0.82–0.89, $p < 0.001$). Coronal restorations were compared with direct composite restorations. Indirect restorations had 77% lower incidence of further treatments (IRR 0.23, 95% CI 0.15–0.35, $p < 0.001$). In contrast, temporary (IRR 1.74, 95% CI 1.29–2.35, $p < 0.001$) and GIC (IRR 1.41, 95% CI 1.19–1.66, $p < 0.001$) restorations had a higher incidence of further treatments. Incidence rate of further treatments for RCTT with amalgam restorations did not differ statistically from RCTT with composite restorations. Also, no significant differences were found by operator or jaw. Expected average number of further treatments is described for restorative materials and age categories in Fig. 3. This value ranged from 0.65 for patients aged 18–29 years to 1.01 for patients aged 65+ years. Absolute differences were low between all age groups. A broader range was found for restorative materials. For instance, the expected average number of further treatments for RCTT with indirect restorations was 0.22, while it was 0.95 for RCTT with direct composite restorations.

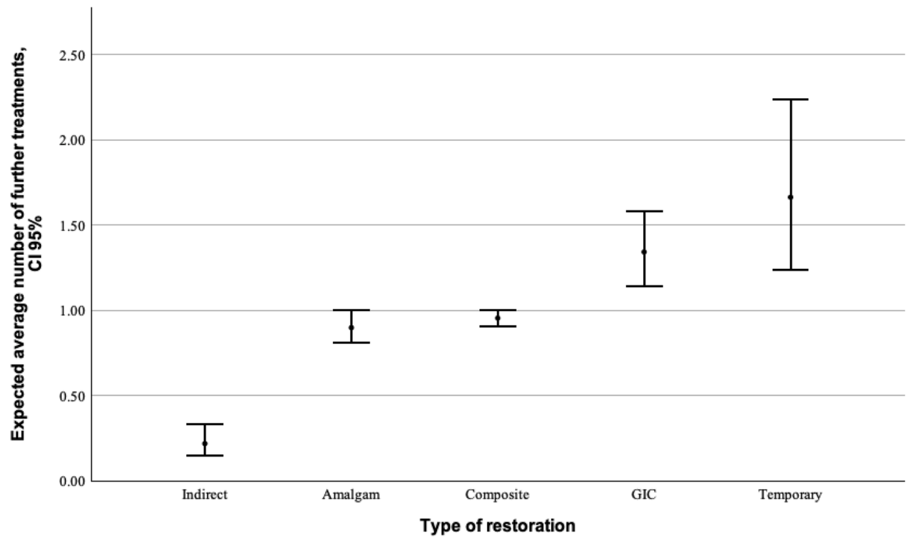
3.3. Hazard of further treatments by patient-, tooth-, and operator-related factors

Influence of patient-, tooth-, and operator-related factors on further treatments was investigated. Four outcomes were assessed: restorative treatment, extraction, non-surgical retreatment, and surgical retreatment. Type of initial coronal restoration was significantly associated with all outcomes (Fig. 4).

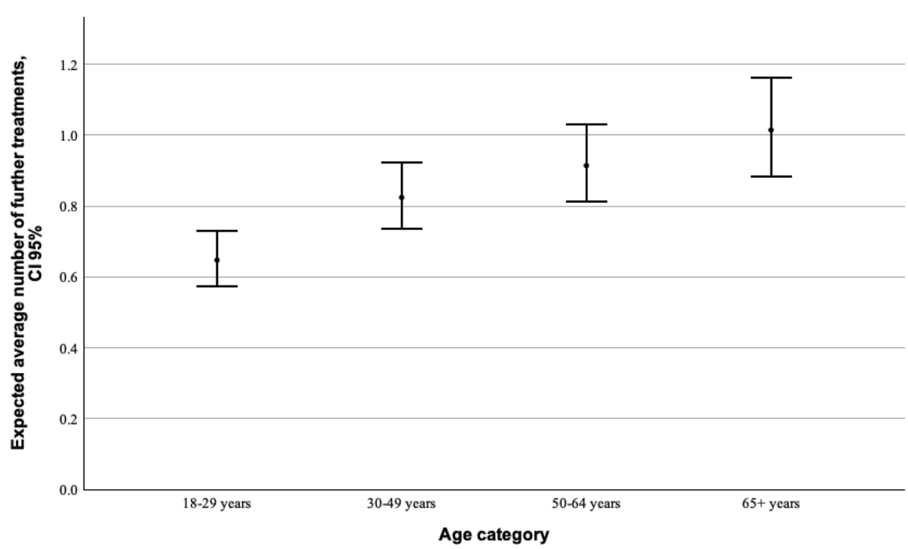
Regarding patient-related factors, men compared with women had 14% lower hazard of further restorative treatment (Table 3; $p < 0.001$). Cox regression model also showed that higher age groups and molar teeth had higher likelihood of further restorative treatment. Indirect restorations had a substantially lower hazard compared with direct composite restorations (HR 0.13, $p < 0.001$). Meanwhile, GIC and temporary restorations had two to eight times higher likelihood of further restorative treatment ($p < 0.001$). Compared with public GDs, RCTT carried out by endodontists had 10% lower hazard ($p < 0.05$) and those performed by dental students 28% higher hazard ($p < 0.05$) of further restorative treatment.

Age, tooth type and coronal restoration were significantly associated with extraction (Table 3). In terms of age, hazard of extraction increased from 1.6 for 30–49 years to 2.7 for 65+ years ($p < 0.001$). Similarly, molar teeth had over 70% higher hazard of extraction than anterior teeth ($p < 0.001$). Teeth with indirect coronal restoration after primary nsRCT presented 64% lower hazard of extraction than teeth with direct composite restoration ($p < 0.05$).

Only a few variables were statistically associated with non-surgical and surgical retreatments (Table 4). Hazard ratios decreased as a function of older age in both outcomes. Yet, statistical significance was found only for the age group of 30–49 years for surgical retreatment (HR 1.94, $p < 0.05$). Men had 35% lower hazard of surgical retreatment than women ($p < 0.05$). Molar teeth had 1.4 times higher hazard of non-surgical retreatment ($p < 0.05$), but markedly lower likelihood of surgical retreatment than anterior teeth (HR 0.10, $p < 0.001$). Temporary restorations had approximately three times higher hazard of non-surgical retreatment ($p < 0.05$). Amalgam restorations had six times higher hazard of surgical retreatment than direct composite restorations ($p < 0.001$). Ultimately, RCTT performed by endodontists compared with public GDs had almost 50% lower hazard of non-surgical



A. Indirect (Mean 0.22, SD 0.05, 95% CI 0.14-0.33), Amalgam (Mean 0.90, SD 0.05, 95% CI 0.81-1.00), Composite (Mean 0.95, SD 0.02, 95% CI 0.91-1.00), GIC (Mean 1.34, SD 0.11, 95% CI 1.14-1.58), Temporary (Mean 1.66, SD 0.25, 95% CI 1.24-2.24).



B. 18-29 years (Mean 0.65, SD 0.04, 95% CI 0.57-0.73), 30-49 years (Mean 0.82, SD 0.05, 95% CI 0.74-0.92), 50-64 years (Mean 0.91, SD 0.06, 95% CI 0.81-1.03), 65+ years (Mean 1.01, SD 0.07, 95% CI 0.88-1.16).

Fig. 3. Expected average number of further treatments after primary non-surgical root canal treatment by type of restoration (A) and age category (B). Error bars indicate 95% CI of the expected means. SD = Standard Deviation.

retreatments ($p < 0.05$), while teeth treated by dental students showed a considerably lower hazard of 68% ($p < 0.05$).

4. Discussion

This study highlighted the incidence and distribution of further restorative treatments, extractions, and endodontic retreatments for RCTT at PDS with a follow-up of 13- to 15-years. As reports on this topic are sparse, our study could offer valuable information on long-term outcomes of RCTT. The mean number of further treatments was 0.96 per tooth. However, these treatments accumulated to approximately half of RCTT which were registered to have at least one further treatment. Molar teeth were over-represented, accounting for 50.9% of all teeth in this study, although this is not unusual as molar teeth are the most often endodontically treated teeth [17–19]. Our study confirms earlier results from a similar register-based study that RCTT are found to have relatively few further endodontic or surgical treatments in a long-term follow-up [8]. In contrast, further restorative treatments were frequently registered. Substantial differences in the frequency of further treatments were observed across tooth types, while the type of initial coronal restoration showed the strongest association with further restorative treatment, extraction, and endodontic retreatment. Thus, the

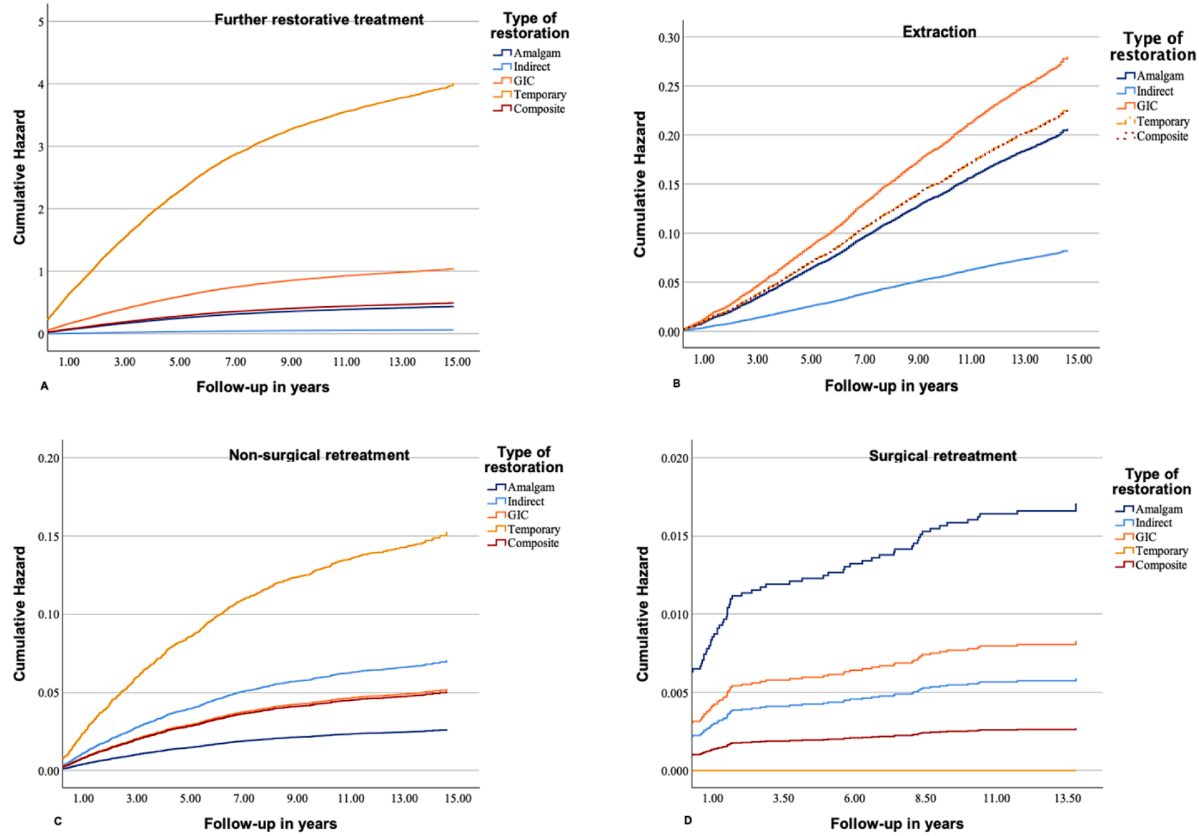


Fig. 4. Cumulative hazard function of further treatments by type of coronal restoration.
A. Further restorative treatment. B. Extraction. C. Non-surgical retreatment. D. Surgical retreatment.

Table 3
Cox regression model of further restorative treatment and extraction after primary non-surgical root canal treatment.

Variable		Further Restoration HR (95% CI)	P-value	Extraction HR (95% CI)	P-value
Sex					
	Women (ref.)				
	Men	**0.86 (0.82–0.90)**	**<0.001**	1.043 (0.974–1.117)	0.226
Age category					
	18–29 years (ref.)				
	30–49 years	**1.18 (1.11–1.25)**	**<0.001**	**1.610 (1.461–1.774)**	**<0.001**
	50–64 years	**1.28 (1.18–1.38)**	**<0.001**	**2.127 (1.893–2.389)**	**<0.001**
	65+ years	**1.55 (1.39–1.73)**	**<0.001**	**2.742 (2.358–3.189)**	**<0.001**
Jaw					
	Maxilla (ref.)				
	Mandible	0.98 (0.93–1.03)	0.489	0.941 (0.876–1.009)	0.089
Tooth type					
	Anterior (ref.)				
	Premolar	1.04 (0.96–1.12)	0.371	1.020 (0.909–1.145)	0.738
	Molar	**1.21 (1.12–1.31)**	**<0.001**	**1.736 (1.557–1.937)**	**<0.001**
Coronal restoration					
	Composite (ref.)				
	Amalgam	0.88 (0.79–0.99)	0.04	0.913 (0.784–1.064)	0.243
	Indirect	**0.13 (0.07–0.25)**	**<0.001**	0.365 (0.198–0.672)	0.001
	Temporary	**7.99 (6.18–10.3)**	**<0.001**	1.238 (0.961–1.593)	0.098
	GIC	**2.09 (1.78–2.47)**	**<0.001**	1.001 (0.580–1.728)	0.997
Operator					
	GD (ref.)				
	GD in PS	1.08 (0.96–1.22)	0.182	1.063 (0.965–1.172)	0.215
	Endodontist	0.90 (0.84–0.97)	0.007	0.924 (0.772–1.106)	0.389
	Dental student	1.28 (1.10–1.49)	0.001	0.956 (1.180–1.457)	0.124

Ref. = reference. P-values under 0.001 are bolded.

null hypothesis (H_0) is rejected.

Further treatments after nsRCT is a topic particularly interesting from the public health point of view. Despite public subsidization of dental care in Nordic countries, financial considerations related to treatment choices and dental care utilization may still contribute to oral health inequalities and inequities [20]. At Helsinki PDS, there were

Table 4
Cox regression model of endodontic retreatments after primary non-surgical root canal treatment.

Variable		Non-surgical retreatment HR (95% CI)	P-value	Surgical retreatment HR (95% CI)	P-value
Sex					
	Women (ref.)				
	Men	0.91 (0.79–1.05)	0.192	0.65 (0.42–0.99)	0.042
Age category					
	18–29 years (ref.)				
	30–49 years	1.07 (0.91–1.27)	0.423	1.94 (1.04–3.61)	0.038
	50–64 years	0.99 (0.79–1.25)	0.976	1.34 (0.64–2.82)	0.434
	65+ years	0.71 (0.49–1.05)	0.083	0.28 (0.06–1.26)	0.097
Jaw					
	Maxilla (ref.)				
	Mandible	0.96 (0.84–1.11)	0.618	0.71 (0.44–1.17)	0.178
Tooth type					
	Anterior (ref.)				
	Premolar	1.24 (0.98–1.57)	0.068	**0.36 (0.22–0.58)**	**<0.001**
	Molar	1.38 (1.09–1.74)	0.006	**0.10 (0.06–0.19)**	**<0.001**
Coronal restoration					
	Composite (ref.)				
	Amalgam	0.52 (0.34–0.79)	0.003	**6.31 (3.16–12.61)**	**<0.001**
	Indirect	1.39 (0.49–3.94)	0.534	2.18 (0.46–10.42)	0.329
	Temporary	3.01 (1.49–6.05)	0.002	n/a	n/a
	GIC	1.03 (0.58–1.83)	0.915	3.06 (1.23–7.65)	0.016
Operator					
	GD (ref.)				
	GD in PS	1.07 (0.89–1.29)	0.479	0.53 (0.23–1.21)	0.130
	Endodontist	0.53 (0.34–0.84)	0.006	0.47 (0.12–1.92)	0.296
	Dental student	0.32 (0.16–0.68)	0.003	1.19 (0.43–3.27)	0.737

n/a = not available. P-values under 0.001 are bolded.

almost equal proportions of men and women receiving primary nsRCTs, being consistent with other large register-based studies in Finland or elsewhere in Scandinavia [21–24]. Approximately 30% of Finnish adults aged over 25 years had at least one visit at PDS in a two-year period, while a similar proportion attended private dental care, and 40% had no appointments [25]. Another study from Finland showed that 57–63% of respondents had attended dental care in the past 12 months in 2001 and 2007 [26]. At Helsinki PDS, we found that RCTT in male patients had 14% lower incidence of further treatments than in female patients. Notably, the hazard of further restorative treatment was lower, mostly explaining the lower overall incidence for men. Apart from the observation that men have lower dental attendance than women in Finland [26], other explanations are limited since sex itself is not considered a biological determinant of endodontic treatment outcome.

In a recent Swedish study, 40% of RCTT were registered to have further treatments in a six-year follow-up [16]. New restorations and extractions were the most common treatments, while endodontic retreatments accounted for only 2% of cases. An insurance-based study from the United States reported similar results, although restorations were excluded from the analysis [9]. Dawson and co-writers [8] found that 23.8% of RCTT had further endodontic or surgical treatment during a 10- to 11-year follow-up. The distribution of further treatments was comparable to our findings, with restorative treatments reported for approximately 40% of teeth, extractions for 20%, non-surgical retreatments for 3.5%, and surgical retreatments for only 1%. Nevertheless, our study period was four to five years longer. It is possible that all further treatments were not registered due to patient- or operator-related reasons. For instance, patients might have not been present at follow-up appointments, and differences between operators on whether to perform endodontic retreatment or extraction could impact the results. However, the highest incidence of endodontic retreatments was found in the first few years following primary nsRCT, which is consistent with the study from Sweden [8]. These findings may reflect the 2006 guideline by the European Society of Endodontology (ESE) which states that the healing of the periapical region can be followed up to four years after the primary treatment [27]. Yet, this guideline was only published during our study period. Nevertheless, retreatment could be indicated in cases of a patient presenting with pain, tenderness to percussion, or other signs of persistent infection in the follow-ups.

As noted above, most of the further treatments observed in this study were restorative treatments. At Helsinki PDS, 6% of posterior two-surface or larger, predominantly composite restorations, required further intervention in the first 12 months [13]. Additionally, large direct restorations compared with indirect restorations may require more further restorative treatments [28]. In the same study, teeth with direct restorations were prone to tooth extraction, with a more significant effect when teeth were root canal treated. We found that RCTT restored with indirect restorations had a significant 67% lower incidence of further treatments than those restored with direct composite. The likelihood of further restorative treatment was almost 90% lower for indirect restorations than for direct composite restorations, indicating that repairs or new restorations were uncommon for indirectly restored teeth. Whether this reflects a lower frequency of fractures or secondary caries is uncertain as clinical parameters were not evaluated in our study. In one study, direct composite restorations have demonstrated favorable long-term success and survival rates [29]. One meta-analysis did not find differences in short-term restorative failures of RCTT between direct composite and indirect restorations, although only two articles were examined [30]. While direct composite restorations constituted a substantial part of the restorations in our study, indirect restorations with cuspal coverage are recommended over direct restorations to prevent fractures and re-infection of the RCTT when the coronal structure of posterior teeth is significantly weakened [31,32]. Our results align with this recommendation, as teeth with indirect restorations compared with direct composite restorations had over 60% lower hazard of extraction. Yet, indirect restorations may not improve outcomes of nsRCT itself, instead being useful when there has been a substantial loss of the tooth structure [33]. Restoring RCTT with indirect restoration is always dependent on the decision of a clinician, thus introducing some bias. There is also some evidence that indirect restorations are associated with higher quality root fillings [22]. This selection bias may favorably affect the outcomes for teeth with indirect restoration. Nevertheless, adequate coronal restoration should always be placed, which is supported by our findings that temporary restorations had three times higher hazard of non-surgical retreatment than direct composite restorations. This may suggest that microleakage of temporary fillings over time will cause re-infection of the tooth [34].

Further, tooth type was significantly associated with further treatments in this study. Molar teeth had 27% higher incidence of further treatments than anterior teeth. A Swedish study at PDS found that 14.3% of molars received further endodontic or surgical treatment within five years of nsRCT, although no other tooth types were included [35]. In our study, molar teeth had 38% higher hazard of non-surgical retreatment than anterior teeth. This could be caused by technical difficulties or untreated canals during primary nsRCT, as success rates for molar teeth are found to be lower than for other tooth types [36,37]. In addition, molar teeth had 1.7 times higher hazard of extraction than anterior teeth, possibly due to the aforementioned reasons. Hence, the lowest survival rates are often found for root canal-treated molar teeth in large register-based studies [7,23]. In addition to intra-operative factors, treatment history, intense occlusal forces, and thus, exposure to fractures could explain the higher risk of extraction for molar teeth.

Older age was associated with an increased incidence of further treatments. Age itself has not been found to have a marked role in outcomes of nsRCT, although more technical complexities may be encountered with obliterated root canals [38]. The higher prevalence of periodontitis or broader treatment history could also explain our results among elderly patients. Accumulation of such systematic diseases as diabetes mellitus could affect periapical healing, potentially influencing the likelihood of further treatments [39]. Taking into account all of these factors, it is hardly surprising that older age was associated with increased likelihood of further restorative treatment or extraction at Helsinki PDS. Older age has been associated with increased risk of extraction in other long-term studies [23,40]. Contrarily, endodontic retreatments were rarely found for patients aged over 65 years; extractions might have been favored by dentists. As relatively few surgical retreatments were investigated, further conclusions should be drawn with caution. Nevertheless, anterior teeth were most frequently subject to surgical retreatment. This aligns with previous findings and is explained possibly by anatomical location or aesthetic demand for preserving natural teeth [41]. At Helsinki PDS, hazard of surgical retreatment was highest for patients aged 30–49 years, in contrast to Stueland et al. [41], who noted a higher frequency of surgical retreatments for patients older than 50 years. Their study was conducted in Norwegian postgraduate clinics of endodontics where the patients were referred for treatment. The difference in the study setting may partly explain these results.

Interestingly, we did not find significant differences between endodontists and other operators in overall incidence of further treatments, despite endodontists typically managing more complex cases [42]. However, differences were found by treatment type. Primary nsRCTs performed by endodontists were associated with approximately 50% lower likelihood of non-surgical retreatment than those performed by public GDs. Whether this reflects superior technical performance remains unclear, as we did not have clinical or radiographic data. Similar results were found in another study comparing endodontists and non-endodontists [9]. Moreover, hazard of non-surgical retreatment was considerably lower for teeth treated by dental students than by public GDs. Success rates of nsRCT for teeth with and without apical periodontitis have been assessed previously at Helsinki PDS, with results of 56.9% and 79.9%, respectively [36]. A recent meta-analysis found similar results for teeth treated by undergraduates [43]. Nevertheless, time and resource limitations may impact negatively on the outcomes by public GDs. Additionally, dental students often work under the supervision of GDs or endodontists.

A major strength of this study is the large number of patients. Register-based studies typically provide robust insights into population-level characteristics and treatment patterns. The reliability of the data is supported by the use of standardized treatment codes registered by dentists as part of routine clinical documentation and remuneration. Consequently, internal validity can be considered high in register-based studies. Patients treated at PDS represent all socioeconomic and age groups, and information on different operators was available. Our findings can therefore be extrapolated to other study settings, although public GDs performed the majority of primary nsRCTs in this study. Nevertheless, several limitations are present in this study. First, we are not aware of the indications for dental treatments. This is a potential source of bias as the clinical decisions may vary between dentists. Another disadvantage of this study is the lack of clinical and radiographic data which limits the interpretability of the results. Radiographic and clinical information such as pre-operative pulpal status, probing depth, sinus tracts, size of periapical radiolucency, or treatment protocols, are found to be associated with outcomes of nsRCT [10,44]. Periapical radiolucency, quality of restoration and tenderness to percussion are also associated with further treatments after nsRCT [16]. Additionally, presence of untreated canals is related to a higher risk of treatment failure [45]. In our study, we only included RCTT with a registration of coronal restoration. The rationale for this is that our objective was to follow-up completed nsRCTs, including coronal restoration. Consequently, many teeth were excluded. This could present a potential selection bias leading to underestimation of early failures and overestimation of favorable outcomes. Due to resource constraints at PDS, some of the restorations intended as definitive might have been placed after 12 months of root canal filling. It is also likely that there were patients who visited private dental care instead of PDS. Another drawback of our study is the limited number of variables. Moreover, focusing on one variable at a time can lead to misinterpretations, as assessing outcomes are more about the sum of its parts rather than a one single predictor. Loss to follow-up also could not be assessed since this study relied solely on register-based data.

Future research should focus on investigating further treatments of RCTT with clinical and radiographic data. This topic is relevant for patient communication, improving outcomes of nsRCT and the efficiency. Identification of clinically significant factors associated with a higher incidence of further treatments could support dentists in treatment planning. This is important as nsRCT remains a favorable option compared with tooth extraction and replacement by implant [46,47]. Consequently, preservation of natural tooth should always be the primary objective of nsRCT.

5. Conclusion

Our study showed that approximately half of RCTT had at least one further treatment after primary nsRCT at Helsinki PDS in a 13- to 15-year follow-up, the most frequent being restorative treatment. Age, tooth type, and type of restoration were significantly associated with incidence of further treatments. Teeth restored with indirect restorations demonstrated a lower likelihood of further restorative treatment or extraction. Our results contribute to raising awareness of further treatments RCTT may require, as repeat interventions impose additional financial burden and demand further time allocation from dentists, patients, and dental care organizations.

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CRediT authorship contribution statement

Milo Väisänen: Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Ulla Palotie:** Supervision, Conceptualization. **Battsetseg Tseveenjav:** Validation, Supervision, Conceptualization.

Declaration of competing interest

We have no conflict of interest to disclose.

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Appendix A

According to the Finnish National Institute for Health and Welfare (THL), the procedures are time-based and tooth specific.

SGA: nsRCT initiation; cleaning and shaping of root canals of the tooth. Includes possible intracanal medication and temporary restoration.

SGB: root canal filling. Includes possible temporary restoration.

Treatment codes for root canal initiation (SGA01 (emergency treatment), SGA02 (one root canal), SGA03 (two root canals), SGA04 (three root canals), SGA05 (challenging root canal initiation), root canal filling (SGB10 (one root canal), SGB20 (two root canals), SGB30 (three or more root canals)), direct restorations (SFA00 (small restoration), SFA10 (one surface), SFA20 (two surfaces), SFA30 (three surfaces), SFA40 (four surfaces)), indirect restorations (SFB10 (one surface), SFB20 (two surfaces), SFB30 (three surfaces), SFB40 (four surfaces), SPC10 (crown), SPC25 (challenging crown), SPC30 (crown/bridge)), hemisection/radectomy (EBA20), apicoectomy (EBA40, EBA45) and tooth extractions (EBA00 (simple extraction), EBA05 (challenging extraction), EBA10 (surgical extraction), EBA12 (challenging/surgical extraction), EBA15 (extractions of many teeth), EBA30 (extraction of root).

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