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ORIGINAL ARTICLE

Interventions in root-filled teeth identified in general dental practice: A 6-year longitudinal observational study

Sara Olsson[1,2] | **Jakob Jonsson Sjögren**[1,2] | **Maria Pigg**[1] | **Helena Fransson**[1] | **Alf Eliasson**[2,3] | **EndoReCo†** | **Thomas Kvist**[4]

[1]Department of Endodontics, Faculty of Odontology, Malmö University, Malmö, Sweden

[2]Dental Research Department, Public Dental Health Service, Örebro, Sweden

[3]Department of Dentistry, Faculty of Medicine and Health, Örebro University, Örebro, Sweden

[4]Department of Endodontology, Institute of Odontology at the Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

Correspondence
S. Olsson, Department of Endodontics, Section 3, Faculty of Odontology, Malmö University, SE-205 06, Malmö, Sweden.
Email: sara.olsson@mau.se

Funding information
The European Society of Endodontology; Dental Research Department of the Public Dental Health Service, Örebro County, Sweden

Abstract

Aim: To investigate what happens to cross-sectionally identified root-filled teeth over a 6-year period, regardless of the time that elapsed since primary root canal treatment, in a cohort of adult patients regularly attending a Public Dental Service. A secondary aim was to investigate how the cumulative events affecting root-filled teeth over the same time were associated with variables obtained from a baseline examination.

Methodology: Adult patients with ≥1 previously root-filled tooth and regularly attending the Public Dental Service in Örebro County were enrolled for study participation in 2015. General dental practitioners examined all identified root-filled teeth in this cohort at baseline using a standardized protocol and were also responsible for further decision-making and treatments. After six years, information on events of the root-filled teeth was collected from dental records. The highest rating (most invasive treatment) on a 5-point ordinal scale was used in the analyses. Regression analyses with stepwise selection were performed for associations between patient- and tooth-related factors and events.

Results: A total of 445 patients with 1007 root-filled teeth were followed the entire observation time. Twenty (2.0%) of the root-filled teeth had endodontic retreatment and 150 (14.9%) were extracted over six years. Among teeth with periapical radiolucency or pain, the majority did not undergo retreatment or extraction; however, the multivariate analysis demonstrated that retreatment or extraction was associated with baseline recordings of teeth with periapical radiolucency ($p < .0001$), tenderness to percussion ($p < .0001$), and poor coronal restoration ($p < .0001$).

Conclusions: This study corroborates the notion that in general dentistry, root-filled teeth with radiological signs of apical disease often remain untreated over time. Furthermore, it also reveals that root-filled teeth presenting with mild pain do not necessarily receive any intervention. However, teeth with baseline signs of apical periodontitis, pain, or inadequate coronal restoration were more likely to have received intervention during the six-year period.

†The researchers within the Endodontic Research Collaboration in Scandinavia contributed to this study.

KEYWORDS

endodontically treated teeth, endodontics, periapical diseases, public health, retreatment, root canal therapy

INTRODUCTION

There is an abundance of reports about factors associated with the outcome of root canal treatment in terms of periapical healing (Gulabivala & Ng, 2023) and tooth retention (Fransson & Dawson, 2023). There are also many epidemiological surveys which demonstrate that root-filled teeth are frequent in adult populations in many countries including Sweden (León-López et al., 2022; Silnovic et al., 2023). However, few studies investigated the clinical course of this vast pool of root-filled teeth over time, which is surely a matter of interest, not only to patients and dentists, but also to third-party stakeholders such as dental health authorities and insurance organizations.

A radiographic radiolucency indicating apical periodontitis is a common feature, seen with a frequency of 39% in root-filled teeth (Tibúrcio-Machado et al., 2021). However, only a fraction (approximately 5%) of the root-filled teeth are symptomatic (Jonsson Sjögren et al., 2019). Longitudinal studies based on repeated radiological examinations suggest that a majority of root-filled teeth, also those with radiological periapical radiolucency, do not receive any additional treatment over time (Kirkevang et al., 2006, 2014; Petersson et al., 2016). Nevertheless, the presence of a periapical radiolucency increases the risk of extraction over time (Razdan et al., 2023).

The clinical management of asymptomatic root-filled teeth with persistent disease has been studied in case-scenario studies, showing low inter-individual agreement among clinicians (Aryanpour et al., 2000; Hülsmann, 1994; Kvist et al., 2004; Reit & Gröndahl, 1988) probably due to uncertainty and complexity involved in the decision-making process (Kvist & Hofmann, 2023).

The influence of pain or other clinical features on the frequency and type of interventions in root-filled teeth has so far not been systematically evaluated. There is also a lack of studies on root-filled teeth in which the general dental practitioner (GDP) makes the clinical and radiographical examination, records the findings, diagnoses, and finally decides and takes responsibility for the management of the root-filled tooth, regardless of whether it is left without intervention, is treated or extracted by the GDP, or referred to a specialist.

The aim of this exploratory longitudinal observational study was to investigate what happens to cross-sectionally identified root-filled teeth, regardless of the time that had elapsed since the primary root canal treatment, over a six-year period in a cohort of adult patients regularly attending a Public Dental Service. The secondary aim was to investigate how the cumulative events affecting root-filled teeth over the same time were associated with variables obtained from a standardized baseline examination.

MATERIALS AND METHODS

The reporting of this observational study complies with the PROBE and STROBE guidelines (Nagendrababu et al., 2023; von Elm et al., 2007).

Study population

Örebro County, Sweden had in 2015 a population of 291,012 (*Statistikdatabasen—Statistics Sweden*, 2023). A total of 23 Public Dental Service clinics are run by Örebro County and provide care for patients of all ages. Four out of 10 inhabitants over the age of 20 regularly visit one or other of these clinics run by the county (Jonsson Sjögren et al., 2019). In 2015, all adult patients (aged ≥20 years) scheduled for a regular check-up in the month of April had their dental radiographs (bitewing, periapical and/or panoramic radiographs taken years 2008–2014) screened for root-filled teeth before the appointment. The number of intra-oral radiographs ranged from single images to full-mouth examinations. If the patient had at least one root-filled tooth, they were eligible for participation and were invited to take part in the study. Patients accepting participation gave written informed consent. The patients contributed with at least one root-filled tooth each.

The baseline examination and standardized recording of findings in 2015 were performed by the GDPs with varying clinical experience. It comprised a clinical examination, intra-oral periapical radiographs and interview-assisted questionnaires on general health issues and pain or discomfort related to the root-filled tooth or teeth during the last 3 months. Patient-related variables were: gender, age, general health dichotomised to healthy or unhealthy (no vs. one or more of diabetes, cardiovascular disease, gastrointestinal disease, rheumatic disease, neurological disease or mental illness), and number of root-filled teeth included in the study. Tooth-related variables were: tooth location (maxilla or mandible), tooth type (incisor, canine, premolar or molar), presence of a radiolucency of endodontic origin (periapical or periradicular), the largest probing depth of the tooth, presence of sinus

tract, presence of swelling, tooth-associated pain or discomfort during the last 3 months, presence of tenderness to percussion or apical palpation, and quality of coronal restoration rated as good or poor (presence of caries, temporary restoration, insufficient marginal integrity or no restoration).

The baseline cohort in the present study is identical to the cohort of a previous cross-sectional study designed to investigate the frequency and characteristics of pain and discomfort associated with root-filled teeth (Jonsson Sjögren et al., 2019). For that study, a sample size calculation was performed using the assumptions relevant to its research questions, and this was the available sample for the current exploratory study.

Data collection

Six years after the enrolment, the patients' dental records were searched by two examiners for information on any interventions in the root-filled teeth during the period. The examiners (S.O. and J.J.S.) are both PhD students in Endodontics with 14–15 years of clinical experience in general dentistry, and one examiner is pursuing a clinical postgraduate program in Endodontics. All data were transferred to a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA). No other specific registrations were conducted during the follow-up other than the baseline examination and any event. The event of each root-filled tooth was categorized on a 5-point ordinal scale, with increasing degree of perceived invasiveness:

0 = No event recorded.

1 = Scheduled for clinical and/or radiographic follow-up examination.

2 = New restoration.

3 = Orthograde or retrograde endodontic retreatment.

4 = Extraction.

If there were several events of a tooth during the period, only the event with the highest number on the ordinal scale (the most invasive intervention) was recorded as the basis for categorization. For example, if a root-filled tooth first had a new coronal restoration performed, then had endodontic retreatment and finally was extracted, the categorization was 'extraction'.

Patients examined at baseline were accepted and included in the study only if they could be followed for the entire six-year period. Inclusion criteria were also recordings of periapical status and of pain status at baseline.

Before data retrieval from the dental records, the two examiners were calibrated for inter-rater agreement concerning categorization of teeth on the 5-point ordinal scale (range 0–4). Twenty-five teeth were randomly selected from the study population, assessed and analysed for inter-rater reliability. The acceptable kappa value was set to a minimum of 0.60. If the value was below 0.60, a discussion among the examiners of the disagreements took place, and a new set of 25 teeth was randomized until $\kappa \geq 0.60$ was attained. Henceforth, all dental records, including those randomly selected for the inter-rater analysis, were distributed between the examiners and reviewed independently.

Ethical considerations

The regional Ethics Review Board in Uppsala (Dnr: 2014/197), the regional Committee for Ionizing Radiation Protection in Örebro and the regional Public Dental Health Service in Örebro County approved the original study (Jonsson Sjögren et al., 2019) and an amendment was approved by the Swedish Ethical Review Authority for this study (Dnr: 2021-00120). All participants signed an informed consent form and did not receive any monetary compensation for study participation.

Statistical analyses

All data from baseline in 2015 and cumulative event registrations at the six-year follow-up were entered into an Excel spreadsheet and then transferred to SAS software, version 9.4 of the SAS System (Cary, NC, USA). Descriptive statistics and frequencies were calculated for baseline variables and events registered at follow-up on individual and tooth levels. Continuous variables were described with mean, SD, median and range and categorical variables with *n* and %.

A dichotomization of the dependent variable was carried out in order to implement the regression analyses. Two different dichotomization alternatives were applied:

I No event recorded or scheduled for follow-up (0, 1) *versus* new restoration, endodontic retreatment or extraction (2, 3 and 4).

II No event recorded, scheduled for follow-up or new restoration (0, 1 and 2) *versus* endodontic retreatment or extraction (3 and 4).

For each of the two dichotomization alternatives, univariate and multivariate analyses were carried out. Due to the anticipated dependency between teeth within a patient, a model that takes the dependency into account was adopted using a generalized estimating equation (GEE). For multivariate analysis, a forward stepwise logistic regression was used to select independent predictors of outcome. Only predictors for which the association to the event rendered

a *p*-value of <.10 in the univariate analysis were included in the forward stepwise logistic regression. At each step of adding a variable, any potential predictor not significant at $p = .05$ was eliminated. To test the goodness of fit for the model, the AUC (area under ROC curve) was calculated.

Before data retrieval, inter-rater reliability was analysed with Cohen's Kappa using SPSS 27 (IBM Corporation, Armonk, NY, USA).

RESULTS

A total of 550 patients with 1256 root-filled teeth were identified as eligible and accepted participation in 2015. At follow-up 6 years later, 445 (80.9%) patients with 1007 root-filled teeth were included. Figure 1 displays a flow chart of participants and reasons for nonparticipation. The gender distribution was 251 (56.4%) women and 194 (43.6%) men. Age ranged from 21 to 87 years with a mean of 60.3 years. Each patient contributed with 1–9 teeth. A dropout analysis showed that excluded patients were significantly more often male ($p = .041$), older ($p = .0002$) and unhealthy ($p = .0001$). Furthermore, relatively less incisors and more molars were available for inclusion ($p < .0001$). Tables 1 and 2 present demographic data and dropout analysis of the included and excluded patients on both individual and tooth levels, respectively.

Inter-rater agreement

The inter-rater reliability after the first set of 25 teeth was $\kappa = 0.508$. After a consensus discussion and calibration between the two examiners, another set of 25 teeth was reviewed, and $\kappa = 0.662$ was reached. Full data retrieval was then launched.

Distribution of events

Of the included teeth, 20 (2.0%) had endodontic retreatment over the 6 years and 150 (14.9%) were extracted. A new restoration was placed in 230 teeth (22.4%), whereas 85 (8.4%) were scheduled for follow-up and 522 (51.8%) had no event recorded. The distribution of events in relation to recorded baseline variables is shown in Table 3. For teeth with a periapical radiolucency at baseline, 16 (7.5%) had endodontic retreatment and 55 (25.8%) were extracted. Among root-filled teeth that were painful at baseline, 4 (7.7%) had endodontic retreatment and 17 (32.7%) were extracted.

Association between intervention and independent variables

Results of the analyses using the first dichotomization alternative, no event or scheduled for follow-up versus any type of intervention, are displayed in Table 4. In the multivariate analysis molars (odds ratio [OR] = 1.67; 95% CI 1.12–2.48; $p = .012$), teeth with a periapical radiolucency (OR = 1.93; 95% CI 1.40–2.66; $p < .0001$) as well as teeth with poor quality of the coronal restoration (OR = 3.70; 95% CI 2.38–5.88; $p < .0001$) were associated with any type of intervention.

The results of the analyses of the second dichotomization alternative are presented in Table 5. When no event, scheduled for follow-up or a new restoration was dichotomized versus endodontic retreatment or extraction, the multivariate analysis found significant associations with the variable periapical radiolucency (OR = 2.88; 95% CI 1.93–4.29; $p < .0001$), tenderness to percussion (OR = 6.64; 95% CI 2.61–16.85; $p < .0001$) and poor coronal restoration (OR = 2.63; 95% CI 1.64–4.17; $p < .0001$).

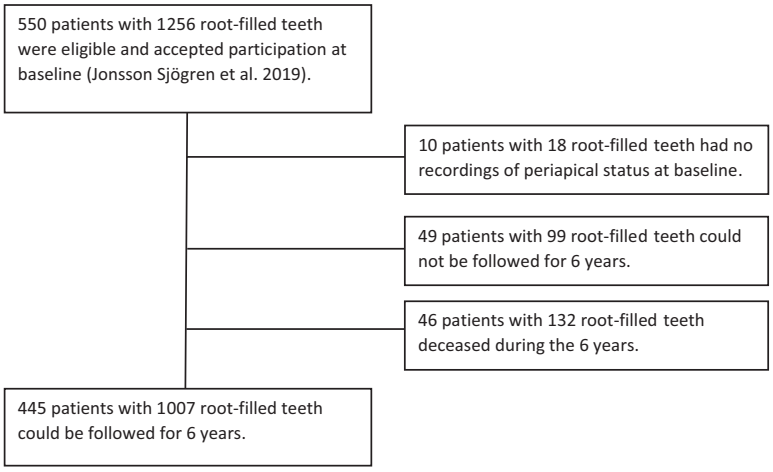

FIGURE 1 Flow chart of participants.

TABLE 1 Demographics and dropout analysis on an individual level at baseline (2015) for all study participants (included) and for patients not fulfilling inclusion criteria (excluded).

Variables			
Patients	**Included *n* = 445**	**Excluded *n* = 105**	***p*-value**
Gender			
Woman; *n* (%)	251 (56.4)	47 (44.8)	
Man; *n* (%)	194 (43.6)	58 (55.2)	.041
Age in years, mean (SD) median (range)	60.3 (12.9)	65.6 (16.7)	.0002
	62 (21; 87)	69 (20; 94)	
Age groups, *n* (%)			
≤50	104 (23.4)	22 (21.0)	
51–70	238 (53.5)	36 (34.3)	
>70	103 (23.1)	47 (44.8)	.0017
General health[a]			
Healthy, *n* (%)	194 (58.4)	29 (34.5)	
Unhealthy[b], *n* (%)	138 (41.6)	55 (65.5)	.0001
Root-filled teeth in study per individual; *n* (%)[c]			
1	201 (45.2)	54 (48.6)	
2	108 (24.3)	24 (21.6)	
3	53 (11.9)	12 (10.8)	
4	34 (7.6)	6 (5.4)	
5	21 (4.7)	7 (6.3)	
6	15 (3.4)	5 (4.5)	
7	6 (1.3)	2 (1.8)	
8	5 (1.1)	1 (0.9)	
9	2 (0.4)	0 (0.0)	

Note: For comparison between groups Fisher's exact test (lowest one-sided *p*-value multiplied by 2) was used for dichotomous variables and the Mantel–Haenszel chi-square test was used for ordered categorical variables and Fisher's nonparametric permutation test was used for continuous variables.

[a]Missing data for 134 patients.

[b]One or more of either diabetes, cardiovascular disease, gastrointestinal disease, rheumatic disease, neurological disease or mental illness.

[c]Six patients contributed with both included and excluded teeth. On the individual level, these patients were categorized as included in the study.

DISCUSSION

In this longitudinal study of patients attending a routine check-up in a Swedish public dental health organization, the majority of root-filled teeth did not receive any intervention in the 6 years after being identified in a cross-sectional study (Jonsson Sjögren et al., 2019). Additionally, and particularly noteworthy, the majority of teeth with radiological signs of disease and/or pain at the baseline examination were not endodontically retreated or extracted.

One of the strengths of the study was that it was performed in a general dental care setting and that the management of the root-filled teeth was done without interference from the researchers. The fact that the amount of baseline data available was predetermined makes the lack of *a priori* sample size calculation based on the current study question a potential limitation of the study. However, a *post hoc* analysis found the numerary basis for the regression analysis to be reasonable, with a large number of events and few independent variables regardless of dichotomization cutoff (Table 3) (Peduzzi et al., 1996).

All patients attending any of the participating clinics during the enrolment were assessed for eligibility and asked for their willingness to participate if they had at least one root-filled tooth, and only those with incomplete data were excluded from the final analyses. Treatment decisions on teeth with low-level or no symptoms or signs of disease may in many cases not be considered urgent but are still not expected to be postponed for several years. A study duration of 6 years was considered adequate to assess if any intervention of the root-filled teeth with signs of disease at baseline was intended by the GDP (Strindberg, 1956). However, it is known that the incidence of retreatments and extractions of root-filled teeth is fairly low but accumulates over time (Dawson et al., 2017), and a longer observational period might have made it possible to identify

TABLE 2 Demographics and dropout analysis on tooth level at baseline (2015) for all study teeth (included) and for teeth not fulfilling inclusion criteria (excluded).

Variables				
Teeth*	**Total *n* = 1256**	**Included *n* = 1007**	**Excluded *n* = 249**	***p*-value**
Gender				
Woman; *n* (%)	717 (57.1)	602 (59.8)	115 (46.2)	
Man; *n* (%)	539 (42.9)	405 (40.2)	134 (53.8)	0.0001
Age in years; mean years (SD) median (range)	64.9 (13.3)	63.6 (12.4)	70.3 (15.0)	<0.0001
	67 (20; 94)	66 (21; 87)	71 (20; 94)	
Age				
≤50	196 (15.6)	167 (16.6)	29 (11.6)	
51–70	597 (47.5)	514 (51.0)	83 (33.3)	
>70	463 (36.9)	326 (32.4)	137 (55.0)	<0.0001
General health[a]				
Healthy; *n* (%)	471 (48.8)	416 (54.3)	55 (27.5)	
Unhealthy; *n* (%)	495 (51.2)	350 (45.7)	145 (72.5)	<0.0001
Tooth location				
Maxilla; *n* (%)	691 (55.0)	547 (54.3)	144 (57.8)	
Mandible; *n* (%)	565 (45.0)	460 (45.7)	105 (42.2)	0.35
Tooth type				
Incisor or canine; *n* (%)	262 (20.9)	189 (18.8)	73 (29.3)	
Premolar; *n* (%)	456 (36.3)	362 (35.9)	94 (37.8)	
Molar; *n* (%)	538 (42.8)	456 (45.3)	82 (32.9)	<0.0001
Periapical radiolucency[b]; *n* (%)				
No	964 (78.4)	794 (78.8)	170 (76.6)	
Yes	265 (21.6)	213 (21.2)	52 (23.4)	0.51
Pocket depth; *n* (%)				
0–5 mm	1115 (88.8)	899 (89.3)	216 (86.7)	
6–12 mm	141 (11.2)	108 (10.7)	33 (13.3)	0.31
Sinus tract[c]; *n* (%)				
No	1240 (99.5)	1000 (99.7)	240 (98.8)	
Yes	6 (0.5)	3 (0.3)	3 (1.2)	0.18
Swelling[d]; *n* (%)				
No	1228 (98.5)	988 (98.5)	240 (98.4)	
Yes	19 (1.5)	15 (1.5)	4 (1.6)	1.00
Pain; *n* (%)				
No	1194 (95.1)	955 (94.8)	239 (96.0)	
Yes	62 (4.9)	52 (5.2)	10 (4.0)	0.57
Tenderness to percussion[e]; *n* (%)				
No	1215 (97.4)	976 (97.3)	239 (97.6)	
Yes	33 (2.6)	27 (2.7)	6 (2.4)	1.00
Tenderness to apical palpation[f]; *n* (%)				
No	1235 (99.0)	993 (99.0)	242 (99.2)	
Yes	12 (1.0)	10 (1.0)	2 (0.8)	1.00
Quality of coronal restoration[g]; *n* (%)				
Poor	195 (15.7)	159 (15.9)	36 (15.1)	
Good	1045 (84.3)	842 (84.1)	203 (84.9)	0.84

Note: For comparison between groups Fisher's exact test (lowest one-sided *p*-value multiplied by 2) was used for dichotomous variables and the Mantel–Haenszel chi-square test was used for ordered categorical variables and the Fisher's nonparametric permutation test was used for continuous variables.

*Variables age, gender and general health are here presented on tooth level as the basis for further analysis presented in Tables 2–4. Missing data for various numbers of teeth: [a]290, [b]27, [c]10, [d]9, [e]8, [f]9, [g]16.

TABLE 3 Distribution of events provided for the root-filled teeth, presented as number (per cent) in relation to all collected variables except age, which is presented as mean value (standard deviation) and median (min–max).

Variable	Total ($n=1007$)	No event ($n=522$)	Scheduled follow-up ($n=85$)	New restoration ($n=230$)	Endodontic retreatment ($n=20$)	Extraction ($n=150$)
Gender						
Woman	602 (100.0)	340 (56.5)	42 (7.0)	111 (18.4)	13 (2.2)	96 (15.9)
Man	405 (100.0)	182 (44.9)	43 (10.6)	119 (29.4)	7 (1.7)	54 (13.3)
Age Mean (SD) Median (range)	63.6 (12.4) 66 (21–87)	65.1 (12.1) 67 (21–87)	62.9 (12.1) 66 (35–84)	62.2 (12.5) 64 (26–87)	54.6 (13.9) 56 (27–74)	62.2 (12.6) 64 (22–85)
Age group						
≤50 years	167 (100.0)	72 (43.1)	15 (9.0)	44 (26.3)	8 (4.8)	28 (16.8)
51–70 years	514 (100.0)	261 (50.8)	46 (8.9)	118 (23.0)	9 (1.8)	80 (15.6)
>70 years	326 (100.0)	189 (58.0)	24 (7.4)	68 (20.9)	3 (0.9)	42 (12.9)
General health[a]						
Healthy	416 (100.0)	209 (50.2)	33 (7.9)	97 (23.3)	8 (1.9)	69 (16.6)
Unhealthy	350 (100.0)	182 (52.0)	33 (9.4)	76 (21.7)	5 (1.4)	54 (15.4)
Tooth location						
Maxilla	547 (100.0)	300 (54.8)	46 (8.4)	109 (19.9)	10 (1.8)	82 (15.0)
Mandible	460 (100.0)	222 (48.3)	39 (8.5)	121 (26.3)	10 (2.2)	68 (14.8)
Tooth type						
Incisor or canine	189 (100.0)	109 (57.7)	20 (10.6)	36 (19.0)	3 (1.6)	21 (11.1)
Premolar	362 (100.0)	213 (58.8)	25 (6.9)	77 (21.3)	5 (1.4)	42 (11.6)
Molar	456 (100.0)	200 (43.9)	40 (8.8)	117 (25.7)	12 (2.6)	87 (19.1)
Periapical radiolucency						
No	794 (100.0)	476 (59.9)	36 (4.5)	183 (23.0)	4 (0.5)	95 (12.0)
Yes	213 (100.0)	46 (21.6)	49 (23.0)	47 (22.1)	16 (7.5)	55 (25.8)
Pocket depth						
0–5 mm	899 (100.0)	471 (52.4)	76 (8.5)	202 (22.5)	20 (2.2)	130 (14.5)
6–12 mm	108 (100.0)	51 (47.2)	9 (8.3)	28 (25.9)	0 (0.0)	20 (18.5)
Sinus tract[b]						
No	1000 (100.0)	521 (52.1)	84 (8.4)	228 (22.8)	19 (1.9)	148 (14.8)
Yes	3 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (33.3)	2 (66.7)
Swelling[c]						
No	988 (100.0)	518 (52.4)	81 (8.2)	226 (22.9)	19 (1.9)	144 (14.6)
Yes	15 (100.0)	4 (26.7)	3 (20.0)	1 (6.7)	1 (6.7)	6 (40.0)
Pain						
No	955 (100.0)	506 (53.0)	77 (8.1)	223 (23.4)	16 (1.7)	133 (13.9)
Yes	52 (100.0)	16 (30.8)	8 (15.4)	7 (13.5)	4 (7.7)	17 (32.7)
Tenderness to percussion[d]						
No	976 (100.0)	516 (52.9)	80 (8.2)	226 (23.2)	19 (1.9)	135 (13.8)
Yes	27 (100.0)	5 (18.5)	4 (14.8)	2 (7.4)	1 (3.7)	15 (55.6)
Tenderness to apical palpation[e]						
No	993 (100.0)	519 (52.3)	82 (8.3)	229 (23.1)	19 (1.9)	144 (14.5)
Yes	10 (100.0)	1 (10.0)	2 (20.0)	0 (0.0)	1 (10.0)	6 (60.0)

(Continues)

TABLE 3 (Continued)

Variable	Total ($n=1007$)	No event ($n=522$)	Scheduled follow-up ($n=85$)	New restoration ($n=230$)	Endodontic retreatment ($n=20$)	Extraction ($n=150$)
Quality of coronal restoration[f]						
Good	842 (100.0)	479 (56.9)	75 (8.9)	170 (20.2)	15 (1.8)	103 (12.2)
Poor	159 (100.0)	42 (26.4)	9 (5.7)	58 (36.5)	4 (2.5)	46 (28.9)

Note: Missing data for various numbers of teeth: [a]241, [b]4, [c]4, [d]4, [e]4, [f]6.

additional baseline risk factors for future intervention. Another limitation of our study was that it was not possible to determine how old the root fillings were and if the teeth had undergone any additional treatments before our baseline recordings.

The methodology of the study was to review the dental records with their inherent constraints and be at the mercy of what was noted by the dentist. The dentist's documentation of any intervention is mandatory by Swedish law and is also a prerequisite for charging the patient. Despite this, the quality of dental records may vary, and examinations, treatment planning and interventions are not always described in sufficient detail, so the interpretation is sometimes difficult. However, the agreement between the two examiners on the patient records and classification according to the 5-point ordinal scale was good. Furthermore, the baseline data were collected prospectively using a standardized questionnaire and were not retrieved from the records, which suggests that the baseline data have high quality. No intra-examiner agreement analysis was performed, and potential variation within the same examiner is therefore unknown.

Some of the included patients may have received interventions, for example, in emergency visits, by dentists outside the Public Dental Service in Örebro County even if the patient remained listed within this organization throughout the observation period. Data on such 'external' interventions would thus not be available to include in the study, however, it seems fair to assume that this only occurred in a few cases since most listed patients attend check-ups regularly within the organization.

The GDPs examined the patients and made the recordings and diagnoses. Baseline data were sometimes missing, particularly about general health, which can be explained by inadequately completed questionnaires. The GDPs were also responsible for any intervention or decision to schedule a follow-up. The dentists' reasoning behind the various decisions and actions evade investigation with our study design. In the dental records, the GDP notes were more or less detailed about the reasons behind the clinical decisions. Most likely, many of the decisions were easy to make and the chosen action was the obvious one, for example, extraction, if the tooth was cracked or fractured. In other cases, the decision-making process was probably more complex. This perhaps applies in particular to cases where there were objective and/or subjective findings indicating ongoing disease and where, despite this, no intervention was undertaken. The choice not to act is typically a result of a more or less articulated balancing of various types and degrees of uncertainty about facts. The interaction between the dentist's and the patient's values and preferences may also have a decisive influence on instituting or refraining from intervention (Kvist & Hofmann, 2023). It is known that patients value the presence of persisting endodontic disease differently and their appreciation of the tooth and the periapical status probably has a great impact on the dentist's/patient's joint decision in individual cases (Kvist & Reit, 2002; Reit & Kvist, 1998). Also the framing, that is, how information about the situation is conveyed to the patient, seems to be of importance (Kvist et al., 2023). The GDP's awareness of contributing data to a study of previously root-filled teeth may have affected their decision-making process, and any framing would conceivably have been in the direction of deciding on or advocating an intervention rather than the direction of no-action as there are recommendations on endodontic retreatment (orthograde or retrograde) when presence of developing or persisting apical periodontitis in root-filled teeth (European Society of Endodontology, 2006; Socialstyrelsen, 2022). Despite this, a majority of the root-filled teeth with signs of apical periodontitis were left without intervention.

The frequency of extractions in this study is similar to the frequencies in recent follow-up studies, ranging from 9% to 18.5% over 6–10 years (Göransson et al., 2021; Kebke et al., 2021; Landys Borén et al., 2015). In a population-based study from Denmark, the frequency of extraction was 13% and retreatments 12% after 10 years (Kirkevang et al., 2014), with a decrease in the frequency of retreatments in a parallel, more recent cohort (Razdan et al., 2023). The difference regarding endodontic retreatments could be explained by the higher frequency of periapical radiolucency in the Danish study, 48% compared to 21% in the present cohort.

TABLE 4 Univariate and multivariate analyses for association between different individual and tooth variables at baseline and the interventions new restoration, endodontic retreatment or extraction (event 2, 3, 4) during the following 6 years (first dichotomization).

				Univariate*		Multivariate**	
Variable	***n* missing**	**Value**	***n* (%) of event**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	***p*-value**
Gender	0						
		Woman	220 (36.5)	1.00			
		Man	180 (44.4)	1.39 (1.03–1.88)	.033		
Age group (years)	0				.074***		
		>70	113 (34.7)	1.00			
		51–70 vs >70	207 (40.3)	1.27 (0.89–1.81)	.19		
		≤50 vs >70	80 (47.9)	1.73 (1.08–2.79)	.023		
General health	241						
		Healthy	174 (41.8)	1.00			
		Unhealthy	135 (38.6)	0.87 (0.61–1.25)	.46		
Tooth location	0						
		Maxilla	201 (36.7)	1.00			
		Mandible	199 (43.3)	1.31 (1.00–1.73)	.053		
Tooth type	0				<.001***	1.00	.004***
		Incisor/canine	60 (31.7)	1.00			
		Premolar vs Incisor/canine	124 (34.3)	1.12 (0.76–1.65)	.57	1.04 (0.70–1.54)	.86
		Molar vs Incisor/canine	216 (47.4)	1.93 (1.30–2.87)	.001	1.67 (1.12–2.48)	.012
Periapical radiolucency	0						
		No	282 (35.5)	1.00		1.00	
		Yes	118 (55.4)	2.26 (1.66–3.06)	<.0001	1.93 (1.40–2.66)	<.0001
Pocket depth	0						
		0–5 mm	352 (39.2)	1.00			
		6–12 mm	48 (44.4)	1.24 (0.85–1.82)	.26		
Sinus tract[a]	4						
		No	395 (39.5)				
		Yes	3 (100.0)				
Swelling	4						
		No	389 (39.4)	1.00			
		Yes	8 (53.3)	1.76 (0.59–5.29)	.31		

(Continues)

TABLE 4 (Continued)

Variable	*n* missing	Value	*n* (%) of event	Univariate*		Multivariate**	
				OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Pain	0						
		No	372 (39.0)	1.00			
		Yes	28 (53.8)	1.83 (1.01–3.31)	.046		
Tenderness to percussion	4						
		No	380 (38.9)	1.00			
		Yes	18 (66.7)	3.14 (1.39–7.08)	.006		
Tenderness to apical palpation	4						
		No	392 (39.5)	1.00			
		Yes	7 (70.0)	3.58 (0.92–13.93)	.066		
Quality of coronal restoration	6						
		Good	288 (34.2)	1.00		1.00	
		Poor	108 (67.9)	4.00 (2.63–6.25)	<.0001	3.70 (2.38–5.88)	<.0001

Note: *p*-values, OR and area under the ROC curve are based on original values and not on stratified groups.

OR is the ratio of the odds for an increase of the predictor of one unit.

Area under ROC curve with 95% CI for multivariable model = 0.66 (0.62–0.69).

[a]Impossible to calculate due to the zero frequency of one level of variable.

*All tests are performed with univariable logistic regression taking into account the dependency within individual (using proc genmod). **Multivariable logistic regression model taking into account the dependency within individual (using proc genmod), including periapical radiolucency, quality of coronal restoration and tooth type. ***p-value for the entire effect/factor/variable.

TABLE 5 Univariate and multivariate analyses for association between different individual and tooth variables at baseline and the interventions endodontic retreatment or extraction (event 3, 4) during the following 6 years (second dichotomization).

				Univariate*		Multivariate**	
Variable	***n* missing**	**Value**	***n* (%) of event**	**OR (95% CI)**	***p*-value**	**OR (95% CI)**	***p*-value**
Gender	0						
		Woman	109 (18.1)	1.00			
		Man	61 (15.1)	0.80 (0.54–1.19)	.27		
Age group (years)	0				.18***		
		>70	45 (13.8)	1.00			
		51–70 vs >70	89 (17.3)	1.31 (0.83–2.07)	.25		
		≤50 vs >70	36 (21.6)	1.72 (0.97–3.03)	.062		
General health	241						
		Healthy	77 (18.5)	1.00			
		Unhealthy	59 (16.9)	0.89 (0.57–1.40)	.62		
Tooth location	0						
		Maxilla	92 (16.8)	1.00			
		Mandible	78 (17.0)	1.01 (0.72–1.43)	.96		
Tooth type	0				.003***		
		Incisor/canine	24 (12.7)	1.00			
		Premolar vs Incisor/canine	47 (13.0)	1.03 (0.61–1.74)	.92		
		Molar vs Incisor/canine	99 (21.7)	1.91 (1.13–3.20)	.015		
Periapical radiolucency	0						
		No	99 (12.5)	1.00		1.00	
		Yes	71 (33.3)	3.51 (2.42–5.10)	<.0001	2.88 (1.93–4.29)	<.0001
Pocket depth	0						
		0–5 mm	150 (16.7)	1.00			
		6–12 mm	20 (18.5)	1.13 (0.66–1.95)	.65		
Sinus tract[a]	4						
		No	167 (16.7)				
		Yes	3 (100.0)				
Swelling	4						
		No	163 (16.5)	1.00			
		Yes	7 (46.7)	4.43 (1.50–13.11)	.007		

(Continues)

TABLE 5 (Continued)

Variable	*n* missing	Value	*n* (%) of event	Univariate*		Multivariate**	
				OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Pain	0						
		No	149 (15.6)	1.00			
		Yes	21 (40.4)	3.66 (2.01–6.67)	<.0001		
Tenderness to percussion	4						
		No	154 (15.8)	1.00		1.00	
		Yes	16 (59.3)	7.76 (3.52–17.12)	<.0001	6.64 (2.61–16.85)	<.0001
Tenderness to apical palpation	4						
		No	163 (16.4)	1.00			
		Yes	7 (70.0)	11.88 (3.03–46.60)	<.001		
Quality of coronal restoration	6						
		Good	118 (14.0)	1.00		1.00	
		Poor	50 (31.4)	2.78 (1.79–4.35)	<.0001	2.63 (1.64–4.17)	<.0001

Note: *p*-values, OR and area under the ROC curve are based on original values and not on stratified groups.

OR is the ratio of the odds for an increase of the predictor of one unit.

Area under ROC curve with 95% CI for multivariable model = 0.69 (0.64–0.73).

[a]Impossible to calculate due to the zero frequency of one level of variable.

*All tests are performed with univariable logistic regression taking into account the dependency within individual (using proc genmod). **Multivariable logistic regression model taking into account the dependency within individual (using proc genmod) including periapical radiolucency, quality of coronal restoration and tooth type. ***p-value for the entire effect/factor/variable.

For patients as well as dentists and third-party stakeholders, any intervention needed for root-filled teeth over time is of interest, hence, the first dichotomization between no or any invasive event (Dawson et al., 2017). Endodontic retreatment and extraction represent more invasive interventions and motivated the second dichotomization (Fransson et al., 2016, 2021).

Overall, molars compared to incisors/canines were more likely to receive any intervention and were also significantly associated with any type of further intervention, along with the presence of periapical radiolucency and poor coronal restoration (Table 4). Repeated restorative treatment is quite frequent in root-filled teeth, especially for teeth restored with direct restorations compared to indirect ones (Dawson et al., 2017). Also, molars generally show a higher prevalence of apical periodontitis (Petersson et al., 2016; Silnovic et al., 2023) and risk of extraction (Fransson et al., 2021; Razdan et al., 2023).

The second dichotomization indicated that periapical radiolucency, tenderness to percussion and poor coronal restoration at baseline were risk factors for endodontic retreatment or extraction, while tooth type did not exhibit any significant association (Table 5). The presence of a radiolucency, and in some cases, tenderness to percussion, may indicate ongoing disease which may cause a person severe physical suffering now or in the future but also distress and anxiety about the condition if not cured (Kvist & Hofmann, 2023).

Among teeth with a periapical radiolucency at baseline, 7.5% had received endodontic retreatment and 25.8% had been extracted. Consequently, our findings are in line with previous findings that a majority of root-filled teeth with periapical radiolucency are left untreated over the years (Kirkevang et al., 2006, 2014; Petersson et al., 1991; Razdan et al., 2023). In comparison, among root-filled teeth without periapical radiolucency, 0.5% had endodontic retreatment and 12% were extracted. Since examinations, diagnoses and management of the teeth in this study were performed by the GDPs, our study validates the finding from several case-scenario studies that periapical radiolucency is neither a requirement nor a sufficient reason for a root-filled tooth to receive an invasive treatment in general dentistry (Aryanpour et al., 2000; Hülsmann, 1994; Kvist et al., 2004; Reit & Gröndahl, 1988; Taha et al., 2019). The uncertainty about time since root canal treatment could potentially bias the regression analyses since the presence of a radiolucency may represent different health states and therefore different bases for decision-making; ongoing healing, persistent infection and inflammation, recurrent infection and inflammation and even presumed healthy tissues after previous apical surgery. A limitation in our study was thus the inability to assess potential changes in periapical radiolucency and clinical features over the 6 years that could conceivably have affected the treatment decision, for example, if radiographic healing or an increase in lesion size was apparent, or if the pain had increased or decreased over time.

However, considering that root-filled teeth are frequent in the adult Swedish population (Frisk et al., 2008), it appears very likely that the vast majority of the root canal treatments had been performed at least 4 years prior to baseline which in most cases would have given them sufficient time to develop a stable healing result prior to inclusion in our study (Strindberg, 1956) and is seems therefore safe to assume that an only very small proportion of teeth were in a phase of 'healing'.

Somewhat more surprising was that among painful root-filled teeth at baseline, only 7.7% had endodontic retreatment and 32.7% were extracted during the follow-up period. In the univariate analysis, pain at baseline was a significant predictor for coronal restoration, retreatment or extraction. Other symptom-related factors with significance were tenderness to percussion, tenderness to apical palpation and swelling. In the multivariate analysis, however, the only symptom-related factor that remained significantly associated with retreatment or extraction was tenderness to percussion ($p < .0001$). For the interpretation, it must be kept in mind that the frequency of many typical clinical findings clearly or potentially related to endodontic disease was very low (sinus tract $n = 3$, tenderness to apical palpation $n = 10$, swelling $n = 15$) except for tenderness to percussion ($n = 27$) (Table 1). The majority of teeth exhibiting any of these findings received some kind of intervention (Table 3).

The reasons for forgoing treatment of painful root-filled teeth could be several. If the only symptom or clinical finding is that the patient is experiencing pain, the origin of pain may very well have a different origin than the persistent periapical disease (Jonsson Sjögren et al., 2019; Nixdorf et al., 2015; Vena et al., 2014). Such diagnoses are usually made after excluding an odontogenic cause with reasonable certainty (Khan et al., 2014). The dentist may have applied further diagnostic measures and perhaps provided treatment targeting an identified nonodontogenic source of the pain, for example, medications or nonpharmacological management of TMD, and such measures were not recorded in this study.

The pain could also have been interpreted as being of low intensity and tolerable to the patient, hence neither intervention was performed nor a decision to follow up the symptoms later on. In a previous study on this cohort by Jonsson Sjögren et al. (2019), for teeth that were painful at the time of examination, the average pain intensity was as low as NRS 1.4 (0–10 scale). The pain may also have appeared only occasionally or have been interpreted as

transitory. In any case, these findings justify further in-depth investigation of this subgroup of patients.

CONCLUSIONS

This study corroborates the notion that in general dentistry, root-filled teeth with radiological signs of apical disease often remain untreated over time. Furthermore, it also reveals that root-filled teeth presenting with mild pain do not necessarily receive any intervention. However, teeth with baseline signs of apical periodontitis, pain or inadequate coronal restoration were more likely to have received additional intervention during the 6-year period.

ENDORECO COLLABORATORS

Lars Bjørndal, Victoria S. Dawson, Helena Fransson, Fredrik Frisk, Peter Jonasson, Thomas Kvist, Merete Markvart, Maria Pigg, Dan Sebring, Emma Wigsten.

AUTHOR CONTRIBUTIONS

Olsson S: Conceptualization, Investigation, Formal Analysis, Methodology, Writing—Original Draft Preparation; Jonsson Sjögren J: Conceptualization, Investigation, Formal Analysis, Methodology, Writing—Review and Editing; Pigg M: Conceptualization, Methodology, Supervision, Writing—Review and Editing; Fransson H: Conceptualization, Methodology, Supervision, Writing—review and editing. Eliasson A: Conceptualization, Methodology, Writing—review and editing. Kvist T: Conceptualization, Methodology, Formal Analysis, Supervision, Writing—Review and Editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The regional Ethics Review Board in Uppsala (Dnr: 2014/197), the regional Committee for Ionizing Radiation Protection in Örebro and the regional Public Dental Health Service in Örebro County approved the original study (Jonsson Sjögren et al., 2019) and an amendment was approved by the Swedish Ethical Review Authority for this study (Dnr: 2021-00120). All participants signed an informed consent form and did not receive any monetary compensation for study participation.

ORCID

Sara Olsson https://orcid.org/0009-0000-1220-0665
Jakob Jonsson Sjögren https://orcid.org/0000-0003-4020-7850
Maria Pigg https://orcid.org/0000-0002-7989-1541
Helena Fransson https://orcid.org/0000-0003-4290-2283
Alf Eliasson https://orcid.org/0000-0001-9240-5053
Thomas Kvist https://orcid.org/0000-0002-2685-3656

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