Treatment Outcome in Endodontics: The Toronto Study—Phases 3 and 4: Orthograde Retreatment

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Abstract

Outcome 4–6 years after retreatment was assessed for Phases 3 and 4 of the Toronto Study. Of 477 teeth retreated, 333 were lost to follow-up, 18 were extracted, and 126 (41% recall, excluding 124 discontinuers) were examined for outcome of healed (periapical index score, ≤2; no signs or symptoms) or diseased. When pooled with Phases 1 and 2, 187 of 229 teeth (82%) were healed. Logistic regression identified significant ($P \leq .05$) preoperative outcome predictors: root filling quality (odds ratio [OR], 4.18; confidence interval [CI], 1.72–10.12; healed: inadequate, 88%; adequate, 66%), perforation (OR, 4.01; CI, 1.28–12.62; healed: absent, 87%; present, 56%), and radiolucency (OR, 3.33; CI, 1.19–9.36; healed: absent, 93%; present, 80%). In teeth with radiolucency, outcome predictors were number of treatment sessions (OR, 12.08; CI, 1.84–∞; healed: one, 100%; ≥2, 77%) and previous root filling quality (OR, 7.68; CI, 2.36–26.89; healed: inadequate, 86%; adequate, 50%). Outcome was better in teeth with inadequate previous root filling, without perforation and radiolucency. Suggested significance of number of treatment sessions in teeth with radiolucency requires validation from randomized controlled trials. *(J Endod 2008;34:131–137)*

Key Words

Apical periodontitis, endodontic treatment, outcome predictors, prognosis, retreatment, root canal therapy, treatment outcome

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The goal of endodontic treatment is to prevent or heal apical periodontitis (AP) (1). In spite of recent advances in endodontics, the goal of treatment is not always achieved, and AP might persist or reoccur after treatment (2, 3). Management of post-treatment AP appears to be a perplexing dilemma, resulting in substantial variation in clinical decisions among clinicians (4).

Management of post-treatment AP includes nonsurgical (orthograde retreatment) and surgical (apical surgery) treatment. Patients should preferably select between these alternatives by weighing their respective benefits and risks (5). The main benefit of interest is the potential to attain the desired outcome, prevention or healing of AP. The potential outcome considered should be supported by sound evidence from clinical studies with current treatment methods. Whereas more than 70 studies have been reported on the outcome of apical surgery (6), only 21 studies published during the past 50 years are available on the outcome of orthograde retreatment (7). A recent review (7) of these studies considered their conformity with methodologic criteria and identified 6 studies (8–13) as providing better evidence than other studies on the outcome of orthograde retreatment. The treatment techniques used in 2 of these selected studies (8, 9) are not consistent with the current ones, reducing the evidence-base for current orthograde retreatment to 4 studies (10–13). The most recent of these studies reported on the outcome of orthograde retreatment in Phases 1 and 2 of the Toronto Study Project (13).

The Toronto Study Project was established in 1993, with the intention to augment the evidence supporting endodontic treatment by prospectively investigating the 4- to 6-year outcome of treatment provided by endodontic residents. The modular design included recall of treated subjects in 2-year phases and pooling of successive samples to improve the power of statistical analysis and the resulting ability to identify significant predictors of outcome. For example, in the successive reports on initial treatment in Phases 1 (1993–1995), 2 (1996–1997), and 3 (1998–1999) (14–16), the number of significant outcome predictors identified by multivariate analysis increased with each added phase. In the previous study on orthograde retreatment in Phases 1 and 2 (13), three significant outcome predictors were identified: preoperative perforation, adequate quality of the previous root filling, and lack of a definitive restoration; all had a negative influence on healing.

The pattern demonstrated in the initial treatment reports suggested that addition of the next phases of the Toronto Study might also identify additional outcome predictors for orthograde retreatment. Thus, the purpose of this study was 2-fold: (1) to systematically assess the 4- to 6-year outcome of orthograde retreatment in Phases 3 and 4 of the Toronto Study and (2) to examine outcome predictors for orthograde retreatment in the pooled samples of Phases 1–4.

Materials and Methods

Study Cohort

The study population comprised all patients referred to the Graduate Endodontic Clinic at the University of Toronto for management of post-treatment AP during the period from January 1998–December 2001. All patients were informed about the causes of post-treatment AP and the benefits and risks associated with orthograde retreatment and the alternatives of apical surgery and extraction and replacement.

Individual subjects were included in the study if they selected orthograde retreatment and signed an informed consent form. The study protocol and the informed consent forms were approved by the University of Toronto Health Sciences Research Ethics Board. The inception cohort consisted of 477 teeth in 383 patients subjected to orthograde retreatment.

Intervention

The protocol of this study was established before the recruitment of subjects and has been described previously (13–17). Graduate Endodontics students performed the treatments under supervision of qualified endodontists. All treatments were performed with the aid of dental operating microscopes (Global Surgical Corporation, St Louis, MO). All preoperative and intraoperative data were coded and recorded in real time by each treatment provider and subsequently entered into the Toronto Study database. The previous root filling was characterized for material (gutta-percha, silver point, paste, or cement), density (absence or presence of voids), and length relative to the radiographic root end (adequate, 0–2 mm or inadequate: short, >2 mm, or long, extruded). Combining density and length, the previous root filling quality was dichotomized as adequate (no voids and adequate length) or inadequate (either voids present, or inadequate length).

Teeth were anesthetized and accessed. The use of specific techniques in each treated case was at the discretion of the treatment providers, solely on the basis of clinical consideration. In general, full-coverage restorations (crowns) were either removed or accessed through. Any caries present was removed, and the teeth were reconstructed as required for proper isolation. Posts were primarily vibrated with ultrasonics (Obtura Spartan, Fenton, MO) and, if required, removed with the Gonon post extractor (FFDM, Bourges, France) or the Ruddle post removal system (SybronEndo Corporation, Orange, CA). Gutta-percha was removed with hand files or rotary nickel-titanium instruments, with or without the use of chloroform. Cements were dispersed with ultrasonics. Silver points and broken instruments were primarily bypassed with hand files and, if possible, retrieved by using ultrasonics, the Masserann system (Micro-Méga, Besançon, France), or the Instrument Removal System (Dentsply Tulsa Dental, Tulsa, OK). In contrast to the previous phases in which perforations were sealed with resin-modified glass-ionomer cements (13), perforations present in the samples of Phases 3 and 4 were sealed with mineral trioxide aggregate (MTA) (ProRoot MTA; Dentsply Tulsa Dental).

Cleaning and shaping were performed in a crown-down manner with hand files and rotary instruments of different designs. Canals were frequently irrigated with 2.5% NaOCl and, on occasion, also with 2% chlorhexidine. Smear layer was removed with 17% ethylenediaminetetraacetic acid (Smear Clear; SybronEndo Corporation). Canals of teeth treated in more than 1 session were medicated with a calcium hydroxide slurry (Pulpdent; Pulpdent Corporation, Watertown, MA) applied with a lentulo spiral (Dentsply Maillefer, Ballaigues, Switzerland). Root fillings were performed with gutta-percha and a variety of sealers. The root filling techniques differed for various treatment sessions during the week, according to a predetermined schedule. Lateral compaction was carried out with finger spreaders (Dentsply Tulsa Dental). Vertical compaction of warm gutta-percha was carried out with heat generators (Touch 'n Heat or System-B; SybronEndo Corporation) for down-packing and an injectable gutta-percha device (Obtura II; Obtura Spartan) for back-filling. In a few teeth, a single gutta-percha cone was used with a glass-ionomer cement sealer (Ketac-Endo; 3M ESPE, Seefeld, Germany), or injectable gutta-percha was used from the apex coronally. Access cavities were temporized, and subjects were referred back to their dentists or undergraduate students for definitive restoration.

Preoperative, intraoperative, and postoperative radiographs were exposed with the aid of Rinn XCP film holders (Dentsply Rinn, Elgin, IL). They were appended to the data sheets that had been kept on file for each subject.

Outcome Assessment

Subjects were recalled 4–6 years after treatment. They were contacted by letter and telephone, encouraged to attend a follow-up examination, and offered compensation for time lost and travel expenses. Attempts were made to locate and contact subjects whose letters were returned. If the subject reported that the tooth had been extracted, the subject's chart at the Faculty of Dentistry was examined to establish the reason for extraction, or for externally referred subjects, the subject was questioned about the reason for extraction.

Follow-up examinations were performed by 2 designated examiners (graduate students), one for Phase 3 (V.M.) and the other for Phase 4 (C. de C.). Symptoms and clinical signs were recorded, and radiographs were exposed to assign a periapical index (PAI) score (18). Both examiners were calibrated for the use of the PAI with the standard calibration kit, and their reproducibility was assessed by using Cohen kappa statistics (19).

Teeth were classified as either healed (PAI $\leq$2 and no symptoms or clinical signs other than tenderness to percussion) or diseased (PAI $\geq$3, or presence of symptoms or clinical signs other than tenderness to percussion). The evaluated unit was the whole tooth, with multi-rooted teeth assigned the highest score of all the roots. Teeth were recorded as functional when absence of any signs or symptoms was noted, independently of the PAI score.

Analysis

Statistical analysis was performed on the Phases 3–4 sample, as well as on the pooled samples from all 4 Phases. It included univariate description to characterize the study material, bivariate analysis of outcome associations with preoperative, intraoperative, and postoperative variables (χ^2 or Fisher exact test) to identify potential outcome predictors, and multivariate analysis (logistic regression models) to identify significant outcome predictors. The complete dataset was analyzed first followed by stratified analysis of the subsamples of teeth without and with preoperative radiolucency. All tests were performed as two-tailed with SPSS 15.0 (SPSS Inc, Chicago, IL) software and interpreted at the 5% significance level. A total of 26 variables were investigated (Table 1).

Results

The examiners of Phases 3 and 4 achieved Cohen kappa scores for intraobserver agreement of 0.96 and 0.84, respectively, indicating very good agreement (19). The interobserver agreement between all the examiners of Phases 1, 2, 3, and 4 ranged from 0.63–0.78, indicating good to very good agreement (19).

Phases 3–4

The inception cohort of 477 teeth in 383 subjects was considerably eroded during the time period of the study. As many as 124 teeth from subjects who could not be contacted (discontinuers) were excluded from the study, whereas 209 teeth could not be examined because the subjects either declined the recall or did not respond (dropouts). The responding population included 144 teeth (41% recall), of which 18 teeth were extracted for restorative (9 teeth), periodontal (6 teeth), or unknown (3 teeth) considerations. The remaining 126 teeth were examined for outcome (study sample). The inception cohort and study sample are compared in Table 1. Characteristics of the lost to follow-up population and the study sample were compared to identify possible response bias. The analysis (not shown) suggested that the study sample

TABLE 1. Univariate Distribution of Investigated Variables in the Study Population

Variables	Phases 3–4		Pooled Phases 1–4	
	Inception cohort, % (n = 477)	Study sample, % (n = 126)	Inception cohort, % (n = 1008)	Study sample, % (n = 229)
Preoperative				
Age (y)				
≤45	50	37	56	35
<45	50	63	44	65
Gender				
Male	39	32	40	34
Female	61	68	60	66
Tooth type				
Anterior	27	28	29	27
Posterior	73	72	71	73
Tooth location				
Maxilla	55	53	59	57
Mandible	45	47	41	43
No. of roots				
1	42	48	43	45
≥2	58	52	57	55
Signs and symptoms				
Absent	62	69	56	62
Present	38	31	44	38
Radiolucency				
Absent	29	35	29	33
<2 mm	17	20	19	18
2–5 mm	33	28	32	32
>5 mm	21	17	20	17
Periodontal defects				
Absent	94	94	94	94
Present	6	6	6	6
Root filling density				
Good	32	33	29	27
Poor	47	48	48	47
Unfilled canal	21	19	23	26
Root filling length				
Adequate	37	42	35	37
Short	55	51	57	56
Long	8	7	8	7
Root filling material				
Gutta-percha	72	73	72	71
Other	28	27	28	29
Perforation				
Absent	94	96	93	92
Present	6	4	7	8
Time since initial treatment (y)				
≥1	92	92	89	87
<1	8	8	11	13
Previous apical surgery				
No	98	98	97	96
Yes	2	2	3	4
Intraoperative				
Treatment sessions				
1	21	24	17	21
≥2	79	76	83	79
Root filling technique				
Lateral compaction	36	33	43	40
Vertical compaction	62	66	55	57
Other*	2	1	2	3
Root filling length				
Adequate	77	73	76	75
Short	10	10	12	11
Long	13	17	12	14
Root filling voids				
Absent	93	94	89	87
Present	7	6	11	13
Sealer extrusion				
No	51	53	50	52
Yes	49	47	50	48

TABLE 1. (Continued)

Variables	Phases 3–4		Pooled Phases 1–4	
	Inception cohort, % (n = 477)	Study sample, % (n = 126)	Inception cohort, % (n = 1008)	Study sample, % (n = 229)
Complications				
No	86	89	85	86
Yes	14	11	15	14
Temporary seal material				
Temporary†	56	52	60	56
Definitive‡	44	48	40	44
Postoperative				
Signs and symptoms				
Absent		91		92
Present		9		8
Radiolucency				
Absent		84		83
Present		16		17
Fracture				
Absent		97		97
Present		3		3
Restoration at follow-up				
Temporary filling		11		11
Definitive filling		29		26
Crown		60		63
Post				
Absent		65		56
Present		35		44

*Modified step-back preparation, single gutta-percha cone with Ketac-Endo sealer.

†Cavit, zinc oxide–eugenol, intermediate restorative material.

‡Amalgam, composite resin, glass-ionomer cement, crown.

was significantly ($P < .05$) older than the lost to follow-up population (dropouts and discontinuers) and included a higher proportion of female subjects.

In total, 104 of 126 teeth (83%) were classified as healed and 22 of 126 teeth (17%) as diseased. Three of the diseased teeth were not properly restored, and 4 were found to be fractured on examination. These fractured teeth were excluded from further analysis because their inclusion could confound the investigation of other variables. Of the remaining 18 diseased teeth, 2 had PAI scores ≤2 (no AP), 4 had smaller lesions than before treatment, 4 had unchanged lesions, and 8 had larger lesions than before treatment. Symptoms or any clinical signs were found in only 8 teeth; 6 of 104 teeth classified as healed had slight sensitivity to percussion, and 2 of 18 teeth classified as diseased (4 fractured teeth excluded) were symptomatic. Thus, a total of 114 of 122 teeth (93%) were fully functional, being free of any clinical signs or symptoms.

In 70 of 122 teeth (4 extracted teeth excluded) the preoperative root fillings were short (>2 mm from the radiographic apex). In 53 of these 70 teeth (76%), canals were successfully retreated closer to the radiographic apex. Preoperative perforations were found in 4 of 122 teeth (2%), and all 4 teeth healed.

Pooled Phases 1–4

The sample of Phases 1–2 was previously characterized (13). The inception cohort of the pooled samples of Phases 1–4 included 1008 teeth, of which 266 were from discontinuers, and 473 were from dropouts (36% recall). The responding population in the pooled sample included 40 extracted teeth and 229 examined teeth (study sample). The inception cohort and study sample are compared in Table 1. The response bias analysis (not shown) suggested that the study sample had a significantly ($P < .04$) higher proportion of older subjects (mean age, 51 vs 41 years) and women (66% vs 58%) than the lost to follow-up population (dropouts and discontinuers).

In total, 187 of 229 teeth (82%) were classified as healed and 42 of 229 teeth (18%) as diseased. Nine of the diseased teeth were not properly restored, and 8 were fractured and subsequently excluded from further analysis to avoid confounding of other variables. Of the remaining 34 diseased teeth, 4 had PAI scores ≤2 (no AP), 9 had smaller lesions than before treatment, 7 had unchanged lesions, and 14 had new or larger lesions than before treatment. Fourteen teeth were associated with symptoms or any clinical signs; 7 of 187 healed teeth had slight sensitivity to percussion, whereas 7 of 34 diseased teeth (8 fractured teeth excluded) were symptomatic. Thus, excluding 8 fractured teeth that were still retained at the time of examination, a total of 207 of 221 teeth (94%) were fully functional.

The bivariate analysis of the pooled sample (Table 2) revealed statistically significant differences in the healed rate, associated with preoperative root filling quality ($P = .001$), perforation ($P = .005$), radiolucency ($P = .012$), and the number of treatment sessions ($P = .020$). Without preoperative radiolucency, 69 of 74 teeth (93%) remained free of disease, and 96% were asymptomatic and functional. Stratified bivariate analysis of this subsample identified no significant associations with any of the examined variables. With preoperative radiolucency, 118 of 147 teeth (80%) healed, and 93% were asymptomatic and functional. Stratified bivariate analysis of this subsample (Table 3) identified statistically significant differences in the healed rate, associated with preoperative root filling quality ($P < .001$), perforation ($P = .007$), and the number of treatment sessions ($P = .014$). Note that without a preoperative perforation, 84% of the teeth with radiolucency healed.

The multivariate analysis (Table 4) identified 3 significant preoperative predictors of persistent AP: adequate quality of the previous root filling (odds ratio [OR], 4.18), perforation (OR, 4.01), and radiolucency (OR, 3.33). Stratified multivariate analysis of the subsample of teeth with preoperative radiolucency (Table 5) identified 2 significant predictors of disease: treatment performed in 2

TABLE 2. Significant Associations between Variables and the Healed Rate 4–6 Years after Orthograde Retreatment in the Pooled Phases 1–4 (n = 221, fractured teeth excluded)

Variables	n	Healed (% n)	*P* value
Preoperative			
Radiolucency			
Absent	74	93	.012
Present	147	80	
Root filling quality			
Adequate	35	66	.001
Inadequate	186	88	
Perforation			
Absent	205	87	.005*
Present	16	56	
Intraoperative			
Treatment sessions			
1	46	96	.020
≥2	175	82	

Bivariate analysis with χ^2.

*This value obtained with Fisher exact test.

or more sessions (OR, 12.08; obtained with exact logistic regression to overcome instability of the model) and adequate previous root filling quality (OR, 7.68).

Preoperative perforations were found in 16 of 229 teeth (7%). Two teeth without preoperative radiolucency remained free of disease. Of the remaining 14 teeth with preoperative radiolucency, 4 teeth sealed with MTA healed, compared with only 3 of 10 teeth (30%) sealed with resin-modified glass-ionomer cements.

Discussion

Evidence from clinical outcome research is essential to support decision making, when patients select between orthograde retreatment, apical surgery, and extraction followed by prosthetic replacement. This prospective cohort study assessed the 4- to 6-year outcome of orthograde retreatment in Phases 3–4 and in the pooled samples of Phases 1–4 of the modular Toronto Study project. The demonstrated ability of the Toronto Study to increase the number of identified outcome predictors by pooling samples of successive phases of initial treatment (14–16) suggested that study of orthograde retreatment in Phases 3–4 might identify additional outcome predictors to those found in the previous study of Phases 1–2 (13).

The compliance of the Toronto Study protocol with strict methodology criteria related to the cohort, intervention, outcome assessment, and analysis has been discussed previously (13–16). The methodology

TABLE 3. Significant Associations between Variables and the Healed Rate 4–6 Years after Orthograde Retreatment in the Pooled Phases 1–4, Stratified for Teeth with Preoperative Radiolucency (n = 147, fractured teeth excluded)

Variables	n	Healed (% n)	*P* value
Preoperative			
Root filling quality			
Adequate	22	50	<.001
Inadequate	125	86	
Perforation			
Absent	133	84	.007
Present	14	50	
Intraoperative			
Treatment sessions			
1	21	100	.014
≥2	126	77	

Bivariate analysis with Fisher exact test.

TABLE 4. Significant Predictors of 4- to 6-Year Outcome of Orthograde Retreatment Assessed in the Pooled Phases 1–4 (n = 221, fractured teeth excluded)

Predictor	OR for disease	95% Confidence interval	*P* value
Preoperative			
Radiolucency			
(0, absent; 1, present)	3.33	1.19–9.36	.022
Root filling quality			
(0, inadequate; 1, adequate)	4.18	1.72–10.12	.002
Perforation			
(0, absent; 1, present)	4.01	1.28–12.62	.017

Multivariate analysis with logistic regression.

is consistent with the second highest level of evidence, but the low recall rate undermines the validity of the results (20). It is noteworthy that greater than 25% of the treated subjects could not be reached at the end point of the study. Many of these subjects might have been recent immigrants at the time of treatment—a common occurrence at the University of Toronto Faculty of Dentistry (3)—who later relocated and could no longer be contacted. In addition, close to 44% of the treated subjects did not respond to the recall, in spite of monetary compensation offered and multiple attempts to contact each nonresponder during a period of 2 years. This poor response too is characteristic of the patient population at the dental school, as repeatedly demonstrated in all the previous Toronto Study reports (13–16), except the one on apical surgery (17). To explore whether the low recall rate might have skewed the results, a response bias analysis was performed. It suggested that the attending population differed from the lost to follow-up population in age and gender; however, because these variables were not identified as outcome predictors in orthograde retreatment, the suggested recall bias was unlikely to affect the results. A further limitation in this study was the specific referral pattern comprising a dental school population. Although case characteristics, treatment decisions, and procedures performed were typical of an endodontic specialty practice, the results might not be generalized beyond the studied cohort. Finally, starting with the Phase 3 cohort, the treatment protocol was modified from that used during the first 2 phases of the Toronto Study. Engine-driven instruments and dental operating microscopes were gradually introduced, and the specific treatment technique described by Schilder (21, 22) was modified in 3 ways: (1) working length was determined on the basis of electronic measurement rather than the radiographic terminus, (2) root canals were shaped with engine-driven instruments rather than reamers, and (3) multiple canals were treated concomitantly rather than in sequence. These modifications were required to comply with the evolution in current endodontic treatment procedures.

TABLE 5. Significant Predictors of 4- to 6-Year Outcome of Orthograde Retreatment in Teeth with Preoperative Radiolucency, Assessed in Pooled Phases 1–4 (n = 147, fractures excluded)

Predictor	OR for disease	95% Confidence interval	*P* value
Preoperative			
Root filling quality (0, inadequate; 1, adequate)	7.68	2.36–26.89	<.001
Intraoperative			
Treatment sessions (0, single; 1, multiple)	12.08*	1.84–infinity	.005

Multivariate analysis with logistic regression.

*Unstable model, exact logistic regression used.

In the Phases 3–4 sample, 83% of the teeth healed, compared with 81% in Phases 1–2 (13). After pooling all 4 samples, 187 of 229 teeth (82%) were assessed as healed on the basis of strict radiographic and clinical criteria. This outcome reflected the chance to achieve complete healing, which is often the goal of orthograde retreatment (5). However, reduction of the pathologic lesion and functional retention might also be considered benefits by patients, when weighing tooth retention against extraction and prosthetic replacement (5). In this regard, it was noted that reduction of a pretreatment lesion was observed in 9 of 221 teeth (4%, fractured teeth excluded), whereas 207 of 221 teeth (94%, fractured teeth excluded) were functional. Thus, patients weighing orthograde retreatment against extraction and replacement should be advised that 4–6 years after retreatment, 82% of the teeth might be healed, but 86% might appear improved, and 94% might remain functional, even if they are not completely healed.

The significant outcome predictors identified by the multivariate analysis included preoperative root filling quality and perforation, both previously identified in Phases 1–2 (13), and preoperative AP. Among teeth with AP, the number of treatment sessions was also identified as an outcome predictor. Restoration and new root filling length (in teeth without perforation), identified in the previous study (13) with less than half the sample size of the present one, were no longer associated with significant differences in outcome in the present study.

Previous root filling quality, a combination of length and density, was the most important outcome predictor. The associated difference in healed rate was entirely attributed to teeth with AP, where a 36% difference was recorded (inadequate, 86%; adequate, 50%). The intracanal microbial flora sustaining post-treatment AP in teeth with inadequate root filling might resemble that of primary AP and be susceptible to orthograde treatment (23). In contrast, the flora in well-filled canals might be more resistant to orthograde treatment (23). Furthermore, in teeth with apparently adequate root fillings, disease might occasionally be sustained by extraradicular biofilms (24, 25), apical cysts (26), foreign-body reactions (27), or undiagnosed root cracks. All of these would be refractory to orthograde treatment.

The healed rate in teeth with a preoperative perforation was 31% lower than in teeth without perforation (absent, 87%; present, 56%). Although still dramatic, this difference in outcome was smaller than the 47% observed in Phases 1–2 (13). Notably, all 4 teeth with perforations included in Phases 3–4 were repaired with MTA, and all 4 healed. In contrast, Phases 1–2 included 12 teeth with perforations, none of which were repaired with MTA, and of which only 5 healed. The favorable response to perforation repair with MTA corroborated the results of a case-series study (28), in which all 16 teeth healed 1 year or longer after perforation repair with MTA. Because of this favorable response, the importance of preoperative perforation as outcome predictor dropped from number 1 in the previous study (13) to number 2. Possibly, addition of subsequent phases of the Toronto Study, in which MTA has been used invariably, might further reduce the impact of preoperative perforations on the outcome of orthograde retreatment.

Unlike in initial treatment, where preoperative AP is the dominant outcome predictor (14–16), in this study AP was the third outcome predictor, associated with a difference of 13% in the healed rate (absent, 93%; present, 80%). Teeth without AP are usually retreated to prevent disease when the root filling is suspect and a new restoration is required. The healed rate in these teeth was lower than the 97% recorded in Phases 1–2 (13) and fell in the lower end of the range (93%–98%) reported in several other studies (8–10). Nevertheless, the favorable outcome justified the elective procedure, and it was apparently unaffected by any of the analyzed variables. In contrast, retreatment in teeth with AP was not an elective procedure, and its outcome was affected by 2 variables. The healed rate in these teeth was improved from the 78% recorded in Phases 1–2 (13), and it fell in the middle of the range (74%–84%) reported in other studies (8, 9, 11).

Importantly, the outcome in teeth with AP was compromised by the presence of 14 teeth with preoperative perforations, of which only 7 healed. In the teeth without perforations, the healed rate was 84%, and this outcome should be routinely communicated to reflect the prognosis for such teeth. In addition, it should be considered that complete healing of AP might require longer than 4–6 years. Indeed, in a study extending to 27 years (29), close to 10% of teeth appeared healed only in the second or third decade after retreatment. In the present study, 4% of all the teeth had persistent lesions that were smaller than before retreatment; if some of these teeth exhibited slower than usual healing dynamics, the healed rate might even improve with time.

A surprising observation for teeth with preoperative AP was the healed rate difference of 23% associated with the number of treatment sessions (one, 100%; two or more, 77%). However, mathematical considerations dictated the use of exact logistic regression, and the 95% confidence interval extending to infinity suggested that the resulting OR might be inaccurate. Furthermore, interventions such as treatment in 1 or 2 sessions should best be compared in well-planned randomized controlled trials and not in cohort studies such as this one (30). Thus, the outcome predictive role of the number of treatment sessions in retreatment of teeth with AP is only suggestive at best and requires confirmation from randomized controlled trials.

When teeth were retreated where the previous root fillings appeared too short, 74% of the canals were renegotiated to an acceptable length, same as in Phases 1–2 (13) and in another previous study (31). Often in such teeth, clinicians suspect a ledge that might be impossible to pass and consider apical surgery as a preferred alternative (5). This study's results suggested that a short root filling should not be considered a technical contraindication to orthograde retreatment. On the contrary, the outcome was better in these teeth than in those in which the previous root fillings appeared adequate.

In summary, 4–6 years after orthograde retreatment, 82% of teeth healed, whereas 94% remained asymptomatic and functional. Addition of Phases 3–4 of the Toronto Study identified an additional significant outcome predictor to the 2 identified in Phases 1–2, whereas another previously identified predictor was no longer significant. The quality of the previous root filling, presence of a perforation, and AP were identified as the outcome predictors. The suggested predictive role of the number of treatment sessions in teeth with preoperative AP requires confirmation from randomized controlled trials.

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