JOURNAL OF ENDODONTICS
Printed in U.S.A.
VOL. 30, NO. 9, SEPTEMBER 2004

CLINICAL RESEARCH

Treatment Outcome in Endodontics: The Toronto Study. Phases I and II: Orthograde Retreatment

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The 4- to 6-year outcome of orthograde retreatment was assessed for Phases I and II of the Toronto Study. In total, 523 teeth in 444 patients were retreated. With 395 teeth lost to follow-up and 25 extracted, 103 teeth (34% recall) were examined by two independent, blinded, calibrated examiners for outcome: "healed" (absence of apical periodontitis, signs, or symptoms) or "diseased" (presence of apical periodontitis, signs, or symptoms). The "healed" rate (81%) differed significantly for preoperative apical periodontitis (absent, 97%; present, 78%) and perforation (absent, 89%; present, 42%). Logistic regression revealed an increased risk of disease for preoperative perforation and adequate root filling quality, and postoperative lack of definitive restoration (odds ratios = 26.5, 6.6, and 14.0, respectively). Without perforation, inadequate intraoperative root filling length was also identified (odds ratio = 6.8). This study suggested that apical periodontitis, although a strong predictor, was secondary to preoperative perforation and root filling quality, and to postoperative restoration, in predicting the outcome of retreatment.

Cross-sectional studies from different countries (1), including the most recent studies (2, 3), clearly demonstrate that more than 30% of all root-filled teeth in the population are associated with apical periodontitis (AP), or "posttreatment disease" (4). The high prevalence of posttreatment disease suggests a great need for treatment of this condition. The main treatment options include orthograde retreatment (retreatment) and apical surgery (surgery) (4). The results of surveys among dentists (5–7) have shown considerable variability in selecting between retreatment and surgery, suggesting that the selection process has been subjective and inconsistent (4–7).

According to the current concepts of evidence-based health care (8), selection between alternative treatments is based on assessment of their respective benefits and risks (4). The main benefit considered is the probability of healing, or the outcome of treatment (4), as demonstrated in clinical studies consistent with a high level of evidence. Such studies are those that conform to specific designs and defined methodology parameters (8, 9). As suggested in a recent review on the outcome of initial treatment of AP (10), the methodology parameters can be grouped into four categories: 1) the cohort (defined at inception of the study, characterized for pattern of referral and case selection, accounted for at endpoint of the study, meeting sample size threshold), 2) intervention or treatment (relevant and acceptable procedures, providers characterized), 3) outcome assessment (blinded, calibrated, meeting follow-up period threshold), and 4) analysis (confounding factors accounted for).

The outcome of retreatment has been reported for more than 50 years, cumulatively including thousands of teeth (Table 1). The reported outcomes have been diverse, similarly to the reported outcomes of initial (first-time) treatment (10), reflecting methodologic variability among the studies and consequent differences in level of evidence. For most studies in Table 1, the data were extracted from larger collections of information that also included initial treatment or apical surgery. Only data pertinent to the assessment of the level of evidence are presented here; for comprehensive information see Friedman (11). The outcomes were construed from those originally reported as follows: 1) combined clinical and radiographic normalcy was classified as "healed"; 2) reduced radiolucency combined with clinical normalcy was classified as "healing"; and 3) absence of signs and symptoms, or clinical normalcy was classified as "functional." Of the reviewed studies, only four (12–15) conform to at least three of the four methodology parameters outlined above; they were selected as satisfying an acceptable level of evidence. This small number of selected studies formed the evidence base for the outcome of retreatment. Clearly, additional studies consistent with current concepts of retreatment are required to broaden that evidence base.

The Toronto Study Project, established in 1993, is a continuous prospective investigation of the 4- to 6-year outcome of endodontic treatment performed by graduate endodontics students in a university clinic environment. Patient recall has been divided into 2-year phases. This modular design provides cumulative data with the completion of each successive phase, with the aim of amassing a sufficient sample to study the prognostic value of various factors.

TABLE 1. Follow-up studies on the outcome of orthograde retreatment

Study	Cases observed	Follow-up (yrs)	Outcome			EBM Criteria			
			Healed (%)	Healing (%)	Functional (%)	Cohort	Intervention	Outcome assessment	Analysis
Strindberg (1956)	**187**	**0.5–10**	**88**			**y**	**y**	**n**	**y**
Grahnén & Hansson (1961)	502*	4–5	83	6		y	n	n	y
Engström et al. (1964)	**153**	**4–5**	**82†**			**y**	**y**	**n**	**y**
Selden (1974)	52	1.5	88†			n	n	n	y
Bergenholtz et al. (1979)	556*	2	75	12		y	n	y	n
Pekruhn (1986)	36	1	83			n	y	n	n
Molven & Halse (1988)	226*	10–17	81			n	n	y	y
Allen et al. (1989)	596	≥0.5	73	12		n	n	n	n
Sjögren et al. (1990)	**266***	**8–10**	**85**			**y**	**y**	**y**	**y**
van Nieuwenhuysen et al. (1994)	561*	≥0.5	78		97	n	n	n	y
Friedman et al. (1995)	128	0.5–1.5	70	23	93	y	y	n	n
Danin et al. (1996)	18	1	28†		78	n	y	n	n
Sundqvist et al. (1998)	**54**	**4**	**74**			**n**	**y**	**y**	**y**
Piatowska et al. (1998)	110	?	43	42	85	n	y	n	n
Kvist & Reit (1999)	47	4	58			y	n	y	n
Chugall et al. (2001)	85	4	79			n	n	y	y

* roots instead of teeth in other studies.
† healed and healing rates not discernible.
Bold font highlights studies meeting at least 3 of 4 evidence quality parameters.
y = yes; n = no.

The outcome of initial treatment in Phase I (1993–1995), and that outcome combined with the outcome of Phase II (1996–1997), have been reported by Friedman et al. (16) and Farzaneh et al. (17), respectively. The outcome was significantly better for teeth treated without preoperative AP than with AP present (16, 17) and for treatment using the Schilder technique than for use of an alternative technique (17), demonstrating the ability of this project to identify significant predictors of outcome.

The objective of this study was to assess the outcome of orthograde retreatment in Phases I and II of the Toronto Study Project. More specifically, the goal was to assess associations between the outcome and the preoperative, intraoperative, and postoperative factors that can be valuable for projecting the prognosis of treatment and prevention of AP in root-filled teeth. Three of the selected studies (12–14) demonstrate the adverse effect of preoperative AP on the outcome. In addition, Sundqvist et al. (15) suggest that the outcome may be better when the preoperative root filling appears inadequate. It was hypothesized, therefore, that the outcome would be better for teeth retreated without preoperative AP than those associated with AP, and in teeth presenting with inadequate root fillings before retreatment than in those with apparently adequate fillings.

MATERIALS AND METHODS

The protocol for the Toronto Study Project was established before the treatment of patients was begun. The methodology has been previously described in detail (16, 17). The methodologic aspects specific to this study are detailed below, whereas the general aspects common to this and the previous studies (16, 17) are only summarized.

The inception cohort consisted of 523 teeth in 444 patients, constituting all orthograde retreatments performed from September 1993 to December 1997. The selection of cases for retreatment was based on patient consultation, wherein the cause of the disease and the treatment alternatives were explained. In all cases, the patients selected retreatment over apical surgery, extraction, or no intervention. There was no systematic preference for either treatment alternative based on tooth characteristics, as long as teeth were considered restorable and periodontally sound. Appropriate informed consent was obtained from all patients before treatment was begun.

Supervised graduate students provided treatment in accordance with a structured protocol. All teeth were treated with the use of magnifying loupes only, without the use of the surgical operating microscope. Full-coverage coronal restorations were either accessed through, or cut in half and discarded. In selected cases, crowns and bridges were removed with either a standard (Premier, Plymouth Meeting, PA) or a spring-loaded (Peerless Crown-A-Matic, Endo-Co, Memphis, TN) removing device and recemented after retreatment. Posts were vibrated ultrasonically (Spartan unit and CPR #1–3 tips, Obtura Spartan, Fenton, MO) and, if necessary, removed with the Gonon post extractor (R. Chïge, Boca Raton, FL). Gutta-percha was removed using Gates-Glidden burs and hand files (Maillefer-Dentsply, Ballaigues, Switzerland); chloroform was used as a solvent if required. Silver points and separated instruments were preferably bypassed with hand instruments and vibrated ultrasonically (CPR #4–8 tips, Obtura Spartan). If bypassed successfully but not removed, they remained embedded in the root filling. When bypassing was unsuccessful, further attempts were made to remove them with specialized extractor devices, such as the Masserann Kit (Medidenta, Woodside, NY). Perforations, when present, were repaired with resin-modified glass ionomer cements, either Vitrebond (3M, St. Paul, MN) or Photac-bond (ESPE, Seefeld, Germany) without placement of an internal matrix. Pastes and cements were gradually dispersed using ultrasonic vibration and removed with hand files. A solvent (Endosolv-R, Septodont, Cedex, France) was used to facilitate removal of resorcinol-formalin. Root canal preparation and filling mainly comprised either flared canal preparation and vertical compaction of warm gutta-percha, as described by Schilder (18, 19), or modified step-back preparation and lateral compaction of gutta-percha (20, 21). In addition, 5% of the teeth were treated using a modified step-back preparation and a single gutta-percha cone with a glass-

ionomer cement sealer (Ketac-Endo, ESPE, Seefeld, Germany). The techniques were quasi-randomized in accordance with a predetermined schedule without inclusion/exclusion criteria. Each technique was performed on specific days of the week, and patient allocation was done according to their availability, not the treatment technique (16, 17).

All preoperative and intraoperative data were uniformly recorded in real time by the providers of treatment, and entered into a database. Preoperative root filling length and density were assessed radiographically. Length was recorded as "adequate" (0–2 mm short of the root end), "short," or "long." Density was recorded as "good" (homogenous appearance, without voids), "poor" (detectable voids), or "missed canal." The length and density were subsequently combined and dichotomized to reflect apparently adequate or inadequate quality of the root filling. The time elapsed since initial treatment also was recorded, as was the presence of preoperative perforation and history of previous endodontic surgery.

The patients were recalled by letter and offered compensation for attending. Efforts were made to find relocated patients and to encourage nonresponders to attend. When any treated teeth had been extracted, patients were questioned to establish the cause, and, for those who received regular care at the Faculty of Dentistry, the records were examined.

Follow-up examinations were carried out by the designated examiners for Phase I (S.A.) and II (M.F.), both similarly calibrated for use of the Periapical Index (PAI) (22). Interexaminer and intraexaminer reliability scores were calculated. The PAI scores were dichotomized to reflect absence (PAI <3) or presence (PAI ≥ 3) of AP. The tooth was the unit of evaluation, with multirooted teeth assigned the highest score of all roots.

Outcome assessment was based on clinical and radiographic measures, and the periapical tissues were classified as "healed" (absence of AP, signs and symptoms other than tenderness to percussion) or as having "disease" (presence of AP, signs or symptoms). Teeth without clinical signs or symptom were considered "functional" regardless of the PAI score.

Sample size estimation was performed (not shown) for several factors, with 80% power and 5% significance. For example, assuming a 15% healed rate differential, 75 recalled teeth would be required in each group to assess association of the outcome with the preoperative root filling quality (adequate or inadequate), whereas 130 teeth would be required in each group to assess the association of the outcome with the number of roots (1 or ≥ 2).

Analysis

Statistical analysis included: 1) univariate description using percent frequencies, 2) bivariate associations between the treatment outcome and preoperative, intraoperative, and postoperative factors, using χ^2 test of proportions and Fisher's exact test, and 3) multivariate analysis to evaluate joint associations among various factors, using logistic regression models. The dependent variable was the dichotomous outcome: healed versus disease. All tests were performed as two-tailed and interpreted at the 5% significance level. Analysis of the complete sample was followed by stratified analyses of teeth treated without the presence of radiolucency and those treated with radiolucency present. Twenty-five factors were investigated in total (Table 2).

RESULTS

As previously reported (16, 17) Cohen's kappa scores for agreement between the examiners for Phase I (S.A.) and Phase II (M.F.) and the coinvestigator (S.F.), as well as the intraexaminer agreements, all varied from 0.7 to 0.9. These scores represented good agreement (16, 17).

The inception cohort of 444 patients and 523 teeth was distributed into the following categories: (1) discontinuers (excluded), 144 teeth in 1 deceased and 114 relocated patients who could not be contacted; (2) dropouts, 251 teeth from 23 patients who declined recall and 193 patients who did not respond; (3) attending, 128 teeth (34% recall rate) from 113 patients, including 103 teeth examined for outcome ("study sample"), and 25 extracted teeth, 2 for periodontal disease, 9 for restorative considerations, and 14 for unknown reasons. The examined study sample is compared to the inception cohort in Table 2. Response bias analysis with respect to preoperative radiolucency ($\chi^2 = 0.59$, $df = 1$, $P = 0.809$) and other factors (results not shown) revealed that the two populations did not differ significantly, except for age.

Eighty-three teeth (81%) were classified as healed. Of the 20 teeth classified as having disease, 4 were found to be fractured; none had been definitively restored. These fractured teeth were excluded from the statistical analysis to avoid their confounding effect on investigation of other prognostic factors. Of all 25 investigated factors, the bivariate analysis (Table 3) identified only two statistically significant associations, with a higher healed rate for retreatment: without than with preoperative radiolucency present, and without than with preoperative perforation present. Six additional factors were associated with "large" ($\geq 10\%$) healed rate differentials that were not statistically significant.

Of the 83 teeth classified as healed, none had tenderness to percussion. Of the 16 teeth classified as having disease (fractured teeth excluded), 7 had signs and symptoms, of which 2 had a PAI score of 1. Of the 14 teeth with PAI ≥ 3, the lesion was either smaller compared with the preoperative size (6 teeth, 43%), unchanged (3 teeth, 21%), or increased/new (5 teeth, 36%). Thus, in total, 96 teeth (93% of the entire study sample, including the 4 fractured teeth) were asymptomatic or fully "functional."

Of the 30 teeth retreated without radiolucency present, 29 teeth (97%) remained healed. Stratified analysis (Table 4) identified three factors associated with "large" healed rate differentials; none of these associations was statistically significant. Of the 69 teeth retreated with radiolucency, 54 (78%) had healed. Stratified analysis (Table 5) identified only one statistically significant association, with a higher healed rate for teeth retreated without than with a perforation present. Seven additional factors were associated with "large" healed rate differentials that were not statistically significant. Note that the healed rate in teeth with radiolucency was 86% if no preoperative perforation was present.

Multivariate analysis (Table 6) identified the preoperative perforation and root filling quality, as well as the restoration at follow-up, as the significant predictors of outcome, with adjusted odds ratios of 26.5, 6.6, and 14.0, respectively. Because a perforation is not commonly present, and given its overwhelming impact in the analysis, the multivariate analysis was repeated excluding the 12 perforated teeth. The results (Table 7) indicated that in teeth retreated without preoperative perforation, intraoperative root filling length (odds ratio = 6.8) was also a significant predictor of outcome.

Of 309 teeth with preoperative root fillings that were too short, 229 (74%) were retreated to adequate length. Furthermore, the

TABLE 2. Univariate distribution of the investigated factors in the treated population

Prognostic factor	Inception cohort % N (N = 523)	Study sample % n (n = 103)
Preoperative		
Age		
≤45 years	62	32
>45 years	38	68
Sex		
male	41	38
female	59	62
Tooth type		
anterior	31	27
posterior	69	73
Tooth location		
maxillary	62	61
mandibular	38	39
No. of roots		
1	43	42
≥2	57	58
Signs and symptoms		
absent	51	52
present	49	48
Radiolucency and size		
absent	28	29
< 2 mm	21	16
2–5mm	32	37
> 5 mm	19	18
Periodontal defects		
absent	93	93
present	7	7
Root filling density		
good	27	20
poor	48	47
unfilled canal	25	33
Root filling length		
adequate	33	32
short	60	63
long	7	5
Root filling material		
gutta-percha	71	65
other	29	35
Perforation		
absent	92	88
present	8	12
Time since initial treatment		
≤1 year	13	18
>1 year	87	82
Previous apical surgery		
no	96	93
yes	4	7
Intraoperative		
Treatment sessions		
1	14	18
≥2	86	82
Root filling technique		
SBLC*	49	48
FPVC†	46	45
other‡	5	7
Root filling length		
adequate	76	77
short	16	12
long	8	11
Root filling voids		
absent	86	77
present	14	23
Sealer extrusion		
no	50	51
yes	50	49
Complications		
no	85	82
yes	15	18
Temporary seal material		
temporary§	16	20
definitive‖	84	80
Postoperative		
Signs and symptoms		
absent		93
present		7
Radiolucency		
absent		83
present		17
Fracture		
absent		96
present		4
Post		
absent		45
present		55
Restoration at follow-up		
temporary filling		10
definitive filling		23
crown		67

* SBLC = modified step-back instrumentation and lateral condensation of gutta-percha.
† FPVC = flared canal preparation and vertical compaction of warm gutta-percha.
‡ Other = modified step-back preparation and obturation with a single cone of gutta-percha.
§ Cavit, ZOE, IRM.
‖ Amalgam, composite resin, glass ionomer, crown.

possibility that the preoperative and intraoperative root filling lengths were associated variables was examined and excluded ($\chi^2 = 0.003$, $df = 1$, $P = 0.960$).

Of the 12 teeth with preoperative perforation, 11 were also associated with radiolucency before retreatment. All 12 teeth were definitively restored; thus, the possibility that the perforation and restoration at follow-up were associated variables—restoration might have been delayed because of perceived poorer prognosis—was excluded.

DISCUSSION

Information on treatment outcome is essential to support decision-making processes related to endodontic treatment. In endodontically untreated teeth with irreversible pulpitis or AP, the reported outcome of treatment is considered when tooth retention (treatment) is weighed against extraction. In root-filled teeth, in addition to the above, the outcome is the basis for selection between alternative treatments: retreatment or surgery (4). Furthermore, in root-filled teeth with AP, the poorer reported outcome compared with initial treatment (11) becomes a more critical consideration in supporting tooth retention (retreatment) versus extraction. In this context, studies on the outcome of orthograde retreatment are most valuable.

This prospective, observational cohort study assessed the 4- to 6- year outcome of retreatment in the modular Toronto Study

TABLE 3. Bivariate analysis of associations between selected factors* and the "healed" rate 4–6 years after orthograde retreatment (n = 99) (fractured teeth excluded)

Prognostic factor	n	Healed (% n)	*P* value
Preoperative			
Radiolucency			
absent	**30**	**97**	**0.034§**
present	**69**	**78**	
Root filling quality			
adequate	19	68	0.076§
inadequate	80	88	
Perforation			
absent	**87**	**89**	**<0.001§**
present	**12**	**42**	
Time since initial treatment			
≤1 year	17	71	0.143§
>1 year	82	87	
Intraoperative			
Treatment sessions			
1	16	100	0.067§
≥2	83	81	
Root filling length			
adequate	78	86	0.321§
inadequate	21	76	
Temporary seal material			
temporary†	21	76	0.321§
definitive‡	78	86	
Postoperative			
Restoration at follow-up			
permanent	92	86	0.081§
temporary	7	57	

* Only factors associated with a healed rate differential of ≥10% are presented.
† Cavit, IRM, ZOE.
‡ Amalgam, composite resin, glass ionomer, crown.
§ Fisher's exact test.
Bold type denotes statistical significance.

TABLE 4. Stratified bivariate analysis of associations between selected factors* and the "healed" rate in teeth treated *without* preoperative apical periodontitis, 4–6 years after orthograde retreatment (n = 30) (fractured teeth excluded)

Prognostic factor	n	Healed (% n)	*P* value
Preoperative			
Tooth type			
anterior	7	86	0.233†
posterior	23	100	
Root filling quality			
adequate	4	75	0.133†
inadequate	26	100	
Time since initial treatment			
≤1 year	7	86	0.233†
>1 year	23	100	

* only factors associated with a healed rate differential of ≥10% are presented.
† Fisher's exact test.

TABLE 5. Stratified bivariate analysis of associations between selected factors* and the "healed" rate in teeth treated *with* preoperative apical periodontitis, 4–6 years after orthograde retreatment (n = 69) (fractured teeth excluded)

Prognostic Factor	n	Healed (% n)	*P* value
Preoperative			
Root filling quality			
adequate	15	67	0.289‡
inadequate	54	82	
Perforation			
absent	**58**	**86**	**0.001‡**
present	**11**	**36**	
Time since initial treatment			
≤ 1 year	10	60	0.207‡
> 1 year	59	81	
Intraoperative			
Treatment sessions			
1	9	100	1.189‡
≥2	60	75	
Root filling length			
adequate	57	83	0.116‡
inadequate	12	58	
Root filling voids			
absent	56	80	0.458‡
present	13	69	
Sealer extrusion			
absent	32	72	0.232†
present	37	84	
Postoperative			
Restoration at follow-up			
permanent	63	81	0.112‡
temporary	6	50	

* only factors associated with a healed rate differential of ≥ 10% presented
† Chi-squared test
‡ Fisher's exact test
Bold type denotes statistical significance.

Project. The methodology has already been discussed in the previous two publications (16, 17), suggesting that the study conformed to the parameters of adequate quality and level of evidence, including cohort, exposure, assessment, and analysis, with the exception of too low a recall rate. Despite the low recall rate, it was suggested by the statistical analysis that the study was not subject to response bias. Although there was a difference in patients' distribution into age groups between the inception cohort and study sample, the study results suggested that age was not a significant predictor of outcome. The cases included in the study were similar to those encountered in a typical endodontic specialty practice, and treatment decisions were consistent with those made by endodontists. Nevertheless, because the pattern of referral in this study was specific to a dental school patient population, the results of this study might not be generalized beyond the selected study cohort.

Using both clinical and radiographic outcome measures, the overall healed rate was 81%. However, 93% of the teeth were asymptomatic and fully functional at the 4- to 6- year follow-up. An asymptomatic functional state, although not a sufficient measure of healing, allows the tooth to be retained. This clear, even if not optimal, benefit should be routinely communicated to patients, particularly when retreatment is weighed against tooth extraction and replacement with a prosthetic device.

The high healed rate (97%) in teeth retreated without AP present compared favorably with the range (93–98%) reported in the selected previous studies (12–14). Retreatment without the presence of AP is essentially an elective procedure, aimed at prevention of potential emergence of disease (4). The excellent outcome observed confirmed the effectiveness and supported the selection of retreatment as a preventive measure in these circumstances. None of the analyzed factors had a significant impact on this outcome; a much larger sample than 30 teeth is required to statistically substantiate the impact of any factor on the outcome of retreatment without AP.

TABLE 6. Logistic regression model of the outcome of orthograde retreatment after 4–6 years (n = 99) (fractured teeth excluded)

Predictor	Adjusted odds ratio	95% confidence interval	*P* value
Preoperative root filling quality (0 = inadequate, 1 = adequate)	**6.61**	**1.42–30.73**	**0.016**
Preoperative perforation (0 = absent, 1 = present)	**26.52**	**5.23–134.42**	**<0.001**
Restoration at follow-up (0 = definitive, 1 = temporary)	**14.00**	**2.09–93.99**	**0.007**

Bold type denotes statistical significance.

TABLE 7. Logistic regression model of the outcome of orthograde retreatment after 4–6 years (n = 87) (fractured teeth and teeth with preoperative perforation excluded)

Predictor	Adjusted odds ratio	95% confidence interval	*P* value
Preoperative root filling quality (0 = inadequate, 1 = adequate)	**7.29**	**1.27–41.80**	**0.026**
Intraoperative root filling length (0 = adequate, 1 = inadequate)	**6.76**	**1.19–38.59**	**0.031**
Restoration at follow-up (0 = definitive, 1 = temporary)	**20.49**	**2.52–166.74**	**0.005**

Bold type denotes statistical significance.

Conversely, the healed rate (78%) in teeth retreated with AP was in the middle (68–84%) of the previously reported range (12–15). Although the bivariate analysis highlighted the negative impact of AP on the outcome, the prognostic value of preoperative AP was not corroborated by the multivariate analysis. This finding was surprising, particularly in view of the previous studies on initial treatment (16, 17), where preoperative AP emerged as the dominant predictor of outcome. A possible explanation is the stronger predictive ability of other prognostic factors that are unique to retreatment. Nevertheless, the outcome in teeth with AP differed significantly for absence and presence of a perforation (86% and 36%, respectively). Thus, when communicating to patients the benefit of retreatment, the clinician can suggest the specific healed rates for teeth with and without perforation, rather than the overall healed rate.

The outcome in teeth with preoperative perforation was drastically poorer. Fuss and Trope (23) associate the prognosis of perforated teeth with three factors—size, location, and time elapsed since occurrence to repair—and suggest that the prognosis is poorer for larger, more crestal, and older perforations. Of the 12 perforations in this study sample, 6 occurred long before retreatment, and 11 had established infection. Considering these characteristics, the poorer outcome in the perforated teeth was consistent with that suggested by Fuss and Trope (23). It should be noted that all the perforations were repaired with resin-modified glass ionomer cement. Mineral trioxide aggregate (Pro-Root MTA, Dentsply Tulsa Dental, Tulsa, OK), shown in case reports to afford healing when used for perforation repair (24, 25), was not available during the course of this study. Possibly, the use of MTA could have been beneficial; however, in the absence of outcome studies specifically addressing the repair of perforations with MTA, the impact of its application remains speculative.

The presence of perforations in 12% of the study sample presented a dilemma for the analysis. The "perforation group" was expected to skew the analysis in a negative direction; therefore, it appeared warranted to exclude this group from analysis of the associations between the outcome and all other factors. Because such exclusion would have further reduced the analyzed sample and the power of the analysis, it was decided to perform the bivariate analyses on the entire sample while performing two multivariate analyses, one with the entire sample and the other excluding the perforation group. The multivariate analysis is more appropriate for identifying significant predictors of outcome than the bivariate analysis, when many variables can potentially affect the outcome.

In 309 of the teeth, the preoperative root filling was more than 2 mm short of the root end. Often in teeth with short root fillings, a ledge is suspected (4), and the possibility of renegotiating the canal(s) beyond is doubtful. Such doubts may skew treatment selection from retreatment toward surgery (4). In the present study, canals were renegotiated to adequate length in 74% of those teeth, corroborating a previous report (26). Clearly, a short root filling should not be considered a technical contraindication to retreatment. Furthermore, among the teeth with AP, the outcome was better when the root filling was inadequate (82% healed). This finding suggested that the canals constituted the infected sites, which, when retreated, could be effectively disinfected and sealed, leading to healing. By contrast, in teeth where the preoperative root filling was adequate (67% healed), persisting infection may have been less susceptible to routine retreatment procedures (15). Another possibility, although less prevalent (4), is that the persisting disease in teeth with adequate root filling was caused by extraradicular infection (27, 28), a true cyst (29, 30), or a foreign body reaction (31). Most of the aforementioned conditions would not respond to orthograde procedures such as retreatment. It is noteworthy that the healing rate (74%) in a previous study (15), where teeth were all apparently well filled, was comparable with that in similar teeth in the present study.

With preoperative perforation excluded, the outcome was better also for retreatment performed to an adequate length. The likelihood that the intraoperative root filling length was dictated by the preoperative length was investigated and rejected. The impact of root filling length in this study is consistent with that observed for initial treatment in the Toronto Study (17) and with the findings of Sjögren et al. (14). By contrast, Sundqvist et al. (15) reported no impact of root filling length on the outcome; however, their analysis may have been restricted by the small sample size.

Regarding postoperative factors, the outcome was poorer when teeth had not been definitively restored. Reference to the restoration in the selected endodontic outcome studies is scarce. Sjögren et al. (14) did not find the restoration to affect the outcome of retreatment. Several cross-sectional studies have attempted to associate the quality of the restoration and the outcome of treatment, with equivocal results (1–3). However, the cross-sectional design is questionable for establishing cause-and-effect relationships between outcome and clinical factors (1). Coronal leakage of bacteria into the filled root canal system has been shown to occur in vitro (32–34) as well as in an animal study (35). Because patients may not carry through with the restoration, and reinfection may ensue, endodontic treatment should be considered a continuum from

disinfection of the root canal system to final restoration (34). This principle must be observed regardless of the division of labor typical of retreatment, which frequently involves different practitioners with specific expertise.

Large but statistically insignificant differences were associated with an additional nine factors. The true outcome impact associated with these factors, if any, may be elucidated when future phases of the Toronto Study Project are completed and the cumulative data lead to increased sample size and, ultimately, increased power of the analysis. Future phases of the Toronto Study Project may also reflect the impact, if any, of adjuncts such as rotary instrumentation and microscopes that greatly facilitate retreatment but were not yet in use at the time the cohort of this study was treated.

Supported in part by the Canadian Academy of Endodtics Endowment Fund.

The authors thank Ms. Tamara Arenovich, Ms. Jewel Randolph, and Ms. Annemarie Polis for their valuable assistance in the preparation of this manuscript.

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