Treatment Outcome in Endodontics: The Toronto Study—Phases 3, 4, and 5: Apical Surgery

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Abstract

Introduction: The long-term outcome of apical surgery performed on root-filled teeth presenting with post-treatment apical periodontitis has been the subject of debate; therefore, current evidence is required to support the prognosis of this important procedure. The objectives of this study were (1) to assess the long-term outcome of apical surgery and (2) to identify significant outcome predictors in Phases 3–5 of the Toronto Study, pooled with the previously reported Phases 1 and 2. **Methods:** The 4- to 10-year outcome of apical surgery was prospectively assessed by a blinded, independent, calibrated examiner and dichotomized as "healed" (periapical index score ≤2 or scar; no signs or symptoms) or "diseased." Teeth presenting without signs or symptoms were classified as "functional." Multivariate analysis was performed to investigate outcome predictors, pooling Phases 3–5 (n = 40) with Phases 1 and 2 (n = 94) for improved power. **Results:** Of 261 treated teeth in the pooled sample, 96 were lost to follow-up, and 31 were extracted. Of the remaining 134 teeth (85% recall, excluding 66 teeth that could not be recalled) examined for outcome, 99 teeth (74%) were healed, and 126 teeth (94%) were functional. Three significant ($P < .05$) outcome predictors were identified: age (odds ratio [OR], 2.5; confidence interval [CI], 1.01–6.00; healed: >45 years, 84%, ≤45 years, 68%), preoperative root-filling length (OR, 3.4; CI, 1.34–8.76; healed: inadequate, 84%; adequate, 68%), and size of the surgical crypt (OR, 1.9; CI, 1.19–3.16; healed: ≤10 mm, 80%; > 10 mm, 53%). **Conclusions:** In this 4- to 10-year cohort study, the outcome was better in subjects >45 years old, teeth with inadequate root-filling length, and crypt size of ≤10 mm. *(J Endod 2010;36:28–35)*

Key Words

Apical surgery, endodontics, healing, outcome assessment, outcome predictors

The universal goal of endodontic treatment is to prevent or cure apical periodontitis (AP), caused by infection of the root canal systems of the affected teeth (1). Epidemiologic studies reveal, however, that 33%–60% of root-filled teeth in the population present with AP (2), suggesting persistence of the primary infection or emergence of infection after treatment (3). Post-treatment AP is preferably treated by orthograde retreatment, unless patient preference or benefit-risk analysis suggests management by way of apical surgery (4). Apical surgery normally comprises periapical curettage followed by root-end resection and filling. In specific cases when bacteria colonize only in the apical ramifications of the canal or outside the canal or when pathosis is sustained by a periapical foreign body (5), the surgical procedure effectively removes the infected site and enhances the chances of healing (6). However, in the majority of teeth, in which bacteria colonize within the entire root canal system, the root-end filling might not effectively prevent persistence or recurrence of AP after the surgical procedure (6). Consequently, complete healing after apical surgery has been reported in 37%–97% of teeth (6). This wide range of reported outcomes, primarily caused by differences in methodology (6), obscures the evidence base for the outcome of apical surgery (6). To overcome this heterogeneity of evidence, the "current best evidence" should be used for "making decisions about the care of individual patients" (7).

In a recent review (6) of 65 studies on the outcome of apical surgery, 9 studies were identified as representing the current best evidence for the outcome of apical surgery (8–16). Three more recent studies are also consistent with an adequate level of evidence (17–19). Even within this selected group of 12 studies, there are important differences in methodology. A major concern in several of the studies (11, 12, 15, 16) is a short follow-up period that cannot capture recurrence of AP in teeth that appear completely healed 1–2 years after surgery. Only 6 of the 12 studies representing the current best evidence for the outcome of apical surgery extend beyond 2 years (8, 10, 13, 14, 17, 18). A further concern is the pooling of subjects presenting different variables into 1 study cohort, disregarding the potential influence of these variables on the outcome of treatment. For example, only 3 of the above 12 studies (9, 10, 13) differentiate between teeth in which AP persisted after initial root canal treatment or after orthograde retreatment, although the difference in healing rates might reach 20% in favor of the latter (13). Similarly, second-time surgery is frequently pooled together with first-time surgery, although the healed rate for the former might be 15%–20% lower than for the latter (14).

One of the aforementioned 12 studies reports on the outcome of apical surgery in Phases 1 and 2 (1993–1997) of the Toronto Study (13). The prospective, modular Toronto Study project was established in September 1993 to expand the evidence supporting endodontic treatment, including apical surgery, by investigating the outcome after a minimum of 4 years after treatment. Subjects have been recalled for follow-up in 2-year phases, and the successive cohorts have been pooled to increase the sample size with

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each new phase. The incremental increase of the sample size in turn improved the power of statistical analysis so as to support the investigation into significant predictors of outcome, as demonstrated in 6 publications on nonsurgical treatment in Phases 1 (1993–1995), 2 (1996–1997), 3 (1998–1999), and 4 (2000–2001) (20–25). The assessment of the 4- to 8-year outcome of apical surgery in Phases 1 and 2 identified 2 significant outcome predictors: The proportion of healed teeth was higher when the existing root-filling length was inadequate and when the preoperative lesion diameter was 5 mm or smaller. Large (≥10%) but statistically nonsignificant differences in the healed rate were observed in relation to 8 additional variables. Addition of the next apical surgery phases was warranted, therefore, to investigate additional outcome predictors with increased power, similar to the pattern demonstrated in the Toronto Study reports on initial treatment and orthograde retreatment (20–25). Because of the low numbers of subjects treated by apical surgery in each phase, it was deemed appropriate to recall subjects of Phases 3, 4, and 5, extending the follow-up period for up to 10 years. Thus, the purpose of this study was 2-fold: (1) to assess healing 4–10 years after apical surgery and (2) to identify significant outcome predictors in the pooled samples of Phases 1–5.

Material and Methods

Study Cohort

The inception cohort comprised 88 subjects who had apical surgery performed in the Graduate Endodontics Clinic at the Faculty of Dentistry, University of Toronto during the period between January 1998 and December 2003 and who consented to participate in the study. A total of 106 teeth were treated. All subjects were given detailed explanation of the benefits and risks associated with apical surgery and with alternative treatments, including orthograde retreatment and extraction followed by prosthetic replacement. They were given ample opportunity to discuss the treatment alternatives and were asked to provide written informed consent before beginning of treatment. The study protocol was approved by the University of Toronto Health Sciences Research Ethics Board. After the initiation of the study, subjects were given the opportunity to withdraw. The inception study cohort is characterized in Table 1.

Intervention

Graduate endodontics residents, closely supervised (1:1 ratio) by qualified endodontists, performed the surgical procedures with the aid of the dental operating microscope (Global Surgical Corporation, St Louis, MO) to enhance visualization. Using standard data sheets, they recorded all clinical and radiographic data pertaining to each treated tooth before (preoperative data) and immediately after (intraoperative data) treatment. A duplicate set of radiographs, taken with an XCP Rinn film holder (Dentsply, Woodbridge, ON, Canada) at a constant exposure and developed in an automatic processing device (DENT-X, Elmsford, NY), was attached to the data sheet. All recorded data was directly transferred to a Microsoft Excel (Microsoft Corp, Redmond, WA) database.

The current surgical procedures used were previously reported (13); they are briefly summarized in Table 2. Coronally extended retrograde retreatment (13) was not performed in this cohort. In a small number of teeth (8.8%), complications occurred at the time of treatment. Sinus exposure was noted twice (2%), injury to the inferior alveolar nerve was noted twice (2%), root cracks were noted twice (2%), and anatomic aberrations were noted 3 times (2.8%). At the completion of treatment, subjects were advised of the importance of the long-term follow-up examination to assess the outcome of treatment and to support the study.

Calibration

The designated examiner for the Phases 3–5 cohort (C.B.) was calibrated with the standard Periapical Index (PAI) calibration set (26). The same calibration set was used by the examiner (N.W.) in the previous apical surgery study of Phases 1 and 2 (13), and the results were compared with the gold standard scores recorded by the more experienced co-principal investigator (S.F.). The Cohen kappa statistic was applied to assess intraexaminer and interexaminer reproducibility at several intervals during the study.

Follow-up Examination

Subjects were mailed recall letters 4–10 years after treatment, encouraging them to attend a follow-up examination and offering reimbursement for time out of work and traveling expenses incurred by attending. Subjects who did not respond were contacted by telephone. Subjects whose letters were returned undelivered and those who could not be reached by telephone were looked up in internet-based directories to find their contact information. Finally, a search company (Private Eyes, Newmarket, ON, Canada) was employed to find the contact information of any outstanding subjects.

Teeth that were extracted during the follow-up period were recorded. The cause for extraction was established by searching the charts of the internally referred subjects, and by contacting the referring dentists of the externally referred patients. The entire inception cohort was accounted for and grouped into categories of "unknown address or deceased" (unable to contact), "declined or ignored the recall" (unwilling to attend), and "attending the recall" (27).

One examiner (C.B.) carried out all the follow-up examinations and recorded the clinical and radiographic findings in a standard data sheet. To minimize bias, the data recording was blinded of the preoperative status of the subjects. The information was then entered into the database. Radiographs were viewed in a random sequence. They were mounted in cardboard slits to block off ambient light emanating from the viewer and examined in a darkened room by using magnification. PAI scores (26) were assigned to all radiographs.

Outcome Measures and Criteria

The presence or absence of signs and symptoms (pain, swelling, sinus tract) and the PAI scores were used as outcome measures. Teeth were classified as healed when (a) clinically, there was absence of signs and symptoms and (b) radiographically, the PAI score was 1 or 2 or there was a typical scar tissue appearance as defined by Rud et al (28). Teeth were classified as diseased when clinical signs and symptoms were present, or when the PAI score was 3 or higher. When it was present alone, tenderness to percussion was not considered as a clinical sign (20). The tooth was considered as the evaluated unit, with multi-rooted teeth assigned the highest PAI scores of their roots. Teeth were considered as functional when absence of any signs or symptoms was noted, regardless of the PAI score.

Analysis

Separate analyses were performed on the Phases 3–5 data and on the pooled dataset from all 5 Phases. A univariate description with percent frequencies was generated to characterize the study material. Significant associations between the outcome and all investigated variables were explored in bivariate analyses (χ^2 or Fisher's exact tests) to identify potential outcome predictors. Multivariate analysis (logistic regression) was then performed. All variables that demonstrated a healed rate differential of ≥10% (considered clinically meaningful) were incorporated into prediction models to identify significant

TABLE 1. Frequencies of Investigated Variables in the Apical Surgery Study Populations

Variables	Phases 3–5		Pooled Phases 1–5	
	Inception cohort, %N (N = 106)	Study sample, %n (n = 40)	Inception cohort, %N (N = 261)	Study sample, %n (n = 134)
Preoperative				
Age				
≤45 y	49	47	51	44
>45 y	51	53	49	56
Gender				
Female	55	53	58	55
Male	45	47	42	45
Tooth type				
Anterior	53	47	46	42
Posterior	47	53	54	58
Tooth location				
Maxilla	77	80	77	78
Mandible	23	20	23	22
Signs and symptoms				
Absent	37	35	34	37
Present	63	65	66	63
Radiolucency				
Diffuse	41	47	39	41
Demarcated	59	53	61	59
Lesion size				
≤5 mm	49	57	54	60
>5 mm	51	43	46	40
Root-filling material				
Gutta-percha	93	90	87	86
Other	7	10	13	14
Root-filling density				
Adequate	75	72	48	63
Inadequate	25	28	52	37
Root-filling length				
Adequate	58	55	48	47
Inadequate	42	45	52	53
Perforation				
Absent	92	90	88	91
Present	8	10	12	9
Previous treatment				
Initial treatment	60	55	62	60
Retreatment	40	45	38	40
Previous apical surgery				
No	91	90	91	90
Yes	9	10	9	10
Time since previous treatment				
≤1 year	48	47	45	38
>1 year	52	53	55	62
Restoration				
Temporary	30	32	30	22
Permanent	70	68	70	78
Full coverage	51	35	50	49
Other*	49	65	50	51
Post				
Absent	61	68	56	54
Present	39	32	44	46
Periodontal defect				
Absent	92	98	92	93
Present	8	2	8	7
Intraoperative				
Procedure				
Apicoectomy	14	12	11	10
Root-end filling	86	88	86	84
Retrograde retreatment			3	6
Flap design				
Sulcular	80	89	81	83
Horizontal	20	11	19	17
Hemostatic agent				
Not used	57	59	59	63
Used	43	41	41	37
Beveled root				
No	15	20	6	6
Yes	85	80	94	94

(*Continued*)

TABLE 1. (*Continued*)

Variables	Phases 3–5		Pooled Phases 1–5	
	Inception cohort, %N (N = 106)	Study sample, %n (n = 40)	Inception cohort, %N (N = 261)	Study sample, %n (n = 134)
Method of cavity prep				
None	14	13	11	11
Bur	2	0	4	0
Ultrasound	84	87	85	89
Root-end filling material				
Super EBA	57	49	59	60
Other[†]	43	51	41	40
Complications				
Absent	90	95	86	89
Present[‡]	10	5	14	11
Root-end filling depth				
≤2 mm	21	24	32	29
>2 mm	79	76	68	71
Antibiotics				
Not prescribed	88	89	68	70
Prescribed	12	11	32	30
Size of bony crypt				
≤10 mm	81	95	81	88
>10 mm	19	5	19	12
Biopsy				
Not obtained	50	55	33	36
Apical granuloma	28	32	50	53
Other[§]	22	13	17	11
Postoperative				
Signs and symptoms				
Absent		98		94
Present		2		6
Mobility				
No		62		85
Yes		38		15
Restoration at follow-up				
Temporary		8		7
Permanent		92		93
Full coverage		70		73
Other*		30		27
Quality				
Satisfactory		72		76
Unsatisfactory		28		24
Restoration				
Same		40		46
Changed		60		54
Post				
Absent		58		46
Present		32		54
Root fracture				
Absent		98		96
Present		2		4

*Temporary or definitive filling.

[†]None placed, amalgam/varnish, intermediate restorative material, composite resin, mineral trioxide aggregate.

[‡]Oral-antral communication, inferior alveolar nerve, perforation of cortical plate(s), crack observed, aberrant anatomy.

[§]Cyst or scar

outcome predictors. Stratified subsamples were analyzed separately when deemed appropriate.

The dependent variable in all analyses was the dichotomous outcome, healed versus disease. All statistical tests were two-tailed, performed with SPSS 16.0 software (SPSS Inc, Chicago, IL) and interpreted at the 5% significance level. A total of 28 preoperative and intraoperative variables were investigated (Table 1).

Results

Examiner Reliability

With the PAI calibration set, the Phase 3–5 examiner's intraobserver Cohen kappa score was $\kappa = 0.87$, indicating very good agreement (29). The interobserver Cohen kappa scores between the Phases 3–5 examiner and the Phases 1 and 2 examiner and the co-principal investigator were $\kappa = 0.71$ and 0.80, respectively, indicating good agreement (29).

Univariate Analysis of This Study (Phases 3–5) and the Pooled (Phases 1–5) Cohorts

The distribution of the Phases 3–5 inception cohort at follow-up is outlined in Table 3. Excluding the subpopulation whose absence was unrelated to the outcome of interest (subjects who were deceased, too ill to attend the follow-up examination, or could not be contacted) (27), the successful recall of 61 of 73 teeth of available subjects represented an 84% recall rate. Approximately one third of the teeth with

TABLE 2. Summary of the Intervention Procedures Performed

Procedure	Instruments or materials used	% of teeth
Anesthesia	Lignospan 2% (Septodont, Brampton, ON, Canada)	100
Basic hemostasis	1:50,000 epinephrine (Septodont)	100
Flap	Ochsenbein-Luebke	80
	Intrasulcular	20
Osteotomy	#6-8 round tungsten-carbide burs under sterile saline irrigation (Brasseler, Savannah, GA)	100
Root-end resection	#170L high-speed surgical burs or surgical bone cutter FG, under sterile saline irrigation (Brasseler)	100
Bevel	Dictated by clinical accessibility to the canals	85
Crypt hemostasis	Epinephrine pellets, Nu gauze, ferric sulfate 15.5% solution	43
Root-end cavity preparation	Ultrasonic, with a variety of tips (Obtura Spartan, Fenton, MO)	86
	None	14
Root-end filling	Super EBA cement (Bosworth Company, Skokie, IL)	57
	IRM (Dentsply, Milford, DE)	1
	Amalgam with varnish (Copalite; Cooley and Cooley, Houston, TX)	2
	Mineral trioxide aggregate (white or grey Pro-Root MTA; Dentsply, Tulsa, OK)	26
	None	14
Sutures	Resorbable (Gut 4-0/5-0; Angiotech, Reading, PA)	18
	Nonresorbable (Tevdek II 4-0/5-0; Sybron Endo, Orange, CA. Or Silk 5-0; Ethicon, Somerville, NJ) removed after 3–7 days	82
Postoperative care	Chlorhexidine 0.12% solution twice daily for 7 days (Periogard; Colgate, Toronto, ON, Canada)	100
Antibiotics	To prevent postoperative infection	11

known outcomes were extracted during the follow-up period for a variety of reasons, mostly unrelated to the outcome of interest. The remaining study sample examined for outcome included 40 teeth, 29 of which (72%) were healed and 11 (28%) had persistent disease at the 4- to 10-year follow-up. One examined tooth with persistent disease was fractured.

The cohort of Phases 1 and 2 was previously characterized (13). The distribution of the pooled inception cohort from Phases 1–5 at follow-up is outlined in Table 3. Excluding the subjects whose absence was unrelated to the outcome of interest (deceased, ill, or unknown address), 165 of 195 teeth of available subjects were successfully recalled (85% recall rate). Approximately 19% of the 165 teeth were confirmed to have been extracted during the follow-up period. The pooled sample examined for outcome included 134 teeth.

The frequencies of variables within the pooled inception cohorts and examined study sample are presented in Table 1. Response bias analysis was performed (not shown), comparing the characteristics of the lost-to-follow-up and attending populations, to examine potential differences in exposure to various risk factors. The pooled attending population had a significantly higher proportion of teeth with the following characteristics: posterior teeth (premolars and molars) ($P < .02$), smaller ($\leq$10 mm) crypt size ($P \leq .04$), and permanent restoration ($P < .01$). Of the 174 histopathologic reports available for the pooled cohort, 130 of 174 (75%) reported "periapical granuloma," 26 of 174 (15%) reported "cyst," and 8 of 174 (4.6%) reported "scar."

Of the 134 examined teeth in the pooled sample, 99 teeth (74%) were healed, of which 8 had a slight sensitivity to percussion. Among the 35 teeth (26%) with persistent disease, the size of the periapical radiolucency was diminished from the preoperative size in 14 teeth (40%), remained unchanged in 5 teeth (14%), and increased in 16 teeth (46%). Clinical signs or symptoms were recorded in 8 of 35 diseased teeth. Thus, a total of 126 of 134 teeth (94%) were classified as functional. Five teeth with persistent disease, revealed by the examination to be fractured, were excluded from further analysis to avoid their confounding effect on the investigation of other variables.

Bivariate and Multivariate Analysis of the Pooled (Phases 1–5) Cohort

The bivariate analysis of the pooled sample is summarized in Table 4. Only variables associated with healed rate differentials of 10% or larger (considered clinically meaningful) are listed. Significant healed rate differences were associated with 3 variables: age ($\leq$45 years, 68%; >45 years, 84%), preoperative root-filling length (adequate, 68%;

TABLE 3. Distribution of the Inception Cohorts at Follow-up for Phases 3 –5 and the Pooled Phases 1 –5

	Phases 3–5		Phases 1–5		
Population	Teeth	Patients	Teeth	Patients	Attendance at follow-up
Inception cohort	106	88	261	226	
Lost to follow-up	2	2	3	3	Deceased or too ill to attend*
	31	23	63	50	Unknown address*
	6	5	17	15	Declined attendance
	6	5	13	12	Did not respond to the recall
Attending	40	35	134	119	Attended, teeth examined
	21†	18	31‡	27	Attended, teeth extracted

*Excluded from the study.

†Reasons for extraction: restorative (6 teeth), periodontal (3 teeth), fracture (5 teeth), traumatic injury (1 tooth), unknown (6 teeth).

‡Reasons for extraction: restorative (13 teeth), periodontal (3 teeth), fracture (7 teeth), traumatic injury (1 tooth), persistent infection (1 tooth), unknown (6 teeth).

TABLE 4. Bivariate Analysis of Selected Variables* Associated with Outcome 4 -10 Years after Apical Surgery for the Pooled Phases 1 –5 Sample (n = 129, after exclusion of 5 fractures)

Variable	Pooled Phases 1–5 n	Healed	*P* value
Preoperative			
Age†			
≤45†	**56**†	**68%**†	**.036**†
>45†	**73**†	**84%**†	
Lesion size			
≤5 mm	78	82%	.073
>5 mm	51	68%	
Root-filling length†			
Adequate†	**60**†	**68%**†	**.035**†
Inadequate†	**69**†	**84%**†	
Perforation			
Absent	118	75%	.456‡
Present	11	91%	
Previous apical surgery			
No	117	79%	.148‡
Yes	12	58%	
Intraoperative			
Root-end filling depth			
≤2 mm	38	84%	.197
>2 mm	91	73%	
Crypt size†			
≤10 mm†	**114**†	**80%**†	**.046**†,‡
>10 mm†	**15**†	**53%**†	
Postoperative			
Restoration at follow-up			
Temporary	9	67%	.437‡
Permanent	120	77%	

Bold type indicates statistically significant variables.

*Variables with a healed rate differential ≥10%.

†Statistically significant variables.

‡Fisher exact test (χ^2 used elsewhere).

TABLE 5. Logistic Regression Model Identifying Significant Predictors of Persistent Disease in the Pooled Phases 1 –5 Sample (n = 129, after exclusion of 5 fractures)

Prognostic variable	OR estimate of persistent disease	95% CI	*P* value
Age (0 = >45 y, 1 = ≤45 y)	2.5	1.01–6.00	.047
Preoperative root-filling length (0 = inadequate, 1 = adequate)	3.4	1.34–8.76	.010
Intraoperative crypt size (0 = ≤10 mm, 1 = >10 mm)	1.9	1.19–3.16	.008

inadequate, 84%), and intraoperative crypt size (≤10 mm, 80%; > 10 mm, 53%). All other variables listed in Table 1 were associated with nonsignificant differences.

The multivariate analysis of the pooled sample (Table 5) revealed an increased risk of persistent disease associated with the same 3 variables identified by the bivariate analysis: subject age younger than 46 years (odds ratio [OR], 2.5; confidence interval [CI], 1.01–6.00), adequate root-filling length (OR, 3.4; CI, 1.34–8.76), and crypt size greater than 10 mm (OR, 1.9; CI, 1.19–3.16).

Discussion

Post-treatment AP, representing persistent, recurrent, and emerged infection after previous endodontic treatment (4), is highly prevalent in the population (2). Patients with post-treatment AP are faced with contrasting alternatives, including nonsurgical or surgical management intended to cure and retain the affected tooth or extraction with possible replacement of the tooth with a prosthetic device. Like in all clinical decision-making junctures, patient autonomy must be respected (30), and the patients encouraged to select their preferred treatment alternative, even when making such a selection is difficult. Information on treatment outcomes based on the current best evidence is essential for assisting patients in this challenging decision-making process. With this in mind, the prospective cohort study of the 4- to 10-year outcome of apical surgery in Phases 3–5 was undertaken to augment the sample from the previous phases (13) of the Toronto Study project so as to strengthen the evidence for the prognosis of apical surgery. The increased power of analysis achieved by pooling of the cohorts of Phases 1–5 was also expected to potentially identify additional outcome predictors beyond those reported with the smaller sample in the previous study (13).

The current study methodology was consistent with that of the previous Toronto Study reports on initial treatment (20–23), retreatment (24, 25), and apical surgery (13). A substantial proportion (37%) of the pooled cohort was lost to follow-up; however, 66 of 261 teeth (25%) could not be recalled for reasons assumed to be unrelated to the outcome of interest (death, illness, unknown address) (27). Exclusion of these 66 teeth effectively reduced the study cohort to 195 teeth, of which 165 teeth (85%) were successfully recalled. Thus, with the prospective cohort design, technologically current intervention, recall rate greater than 80%, and blinded, sufficiently long outcome assessment by a calibrated examiner, the current study ranks high (level 1b) in the hierarchy of evidence for questions related to prognosis and lower (level 2b) in the evidence for questions related to efficacy of therapy (31). It was noteworthy that the proportion of available subjects who chose to attend the follow-up examinations was 2-fold higher than in the previous reports on nonsurgical retreatment (24, 25). The higher response rate reiterated the suggestion that patients who had a tooth treated surgically might be more concerned about the status of that tooth than patients who received nonsurgical treatment (13).

A response bias analysis, performed to explore whether the results could be skewed by the loss to follow-up of 37% of the inception cohort, suggested that the lost to follow-up and attending populations differed significantly in regards to 3 variables, of which one was identified as an outcome predictor. The lower proportion in the attending population of teeth with large (>10 mm) crypt size, a predictor of persistent disease, suggested that the healed rate recorded could be overestimated.

The inception cohort in this study was primarily a university clinic–based population, with the minority of subjects referred from private practices. Considering this specific referral pattern, the results of this study might not be generalized beyond the specific study population, even though treatment decisions and procedures were consistent with the accepted standard of care encountered in a typical endodontic specialty practice. The interventions were fairly consistent between the cohorts of Phases 1 and 2 and Phases 3–5, with an increased use of the operating microscope and mineral trioxide aggregate in the latter. These modifications reflected the evolution in current endodontic surgery procedures.

The rationale for the Toronto Study modular design is the incremental increase of the sample size to improve the power of the statistical analysis. As reported in the Phases 1 and 2 study (13), a sample of 606 teeth would be required for analysis with 80% power at 5% significance

level to support significance of 10% healed rate differentials between groups. As a result of the low prevalence of apical surgery cases in the Graduate Endodontics Clinic at the University of Toronto and the loss to follow-up of approximately one third of the inception cohort, this study sample came considerably short of the above target. Consequently, the power of analysis in the present study was only 23%, increased from 18% in the Phases 1 and 2 study (13).

With 72% of teeth healed in the Phases 3–5 sample, the outcome was only slightly poorer than the 74% healed rate recorded in Phases 1 and 2 (13). In the pooled sample, 99 of 134 teeth (74%) were healed in accordance with the strict radiographic and clinical criteria used for outcome assessment. The 74% chance of complete healing represented the prognosis that patients need to take into account when deliberating apical surgery versus orthograde retreatment. However, when weighing tooth retention via apical surgery against extraction and prosthetic replacement, patients may consider the chance of retained symptom-free function, particularly if the pathologic lesion is also diminished from its preoperative size (4). The study results indicated that as many as 126 of 134 teeth (94%) were functional, of which 113 of 134 teeth (84%) presented with healed or diminished lesions at follow-up. Thus, patients considering the different treatment alternatives for the management of post-treatment AP should be informed about the probabilities for complete healing and retained function. For apical surgery, the probability of asymptomatic function is excellent, which may be considered a sufficient benefit by individual patients. Even with the 31 extracted teeth factored into the calculation, the 126 of 165 symptom-free teeth suggested a 76% chance for retained function 4–10 years after apical surgery. Because about half of the 31 extractions were indicated by restorative and periodontal considerations, it appeared plausible that the functional retention rate could be further improved by use of stringent case selection criteria that exclude teeth with extensive or defective restorations and teeth with advanced periodontal defects (32).

In spite of only a 35% increase in sample size and 5% increase in power, 3 outcome predictors were identified in the pooled study sample compared with 2 in the Phases 1 and 2 study (13). Preoperative root-filling length was reiterated as the major outcome predictor as previously reported (13). Teeth with long or short fillings had a combined healed rate of 84%, as compared with 68% in teeth with adequate root-filling length. As suggested previously (13, 33), healing in teeth with short root fillings could be enabled solely by the surgical resection of the infected portion of the root. In teeth with long root fillings, healing could be enabled by the surgical removal of extruded filling material or dentin chips colonized by microorganisms (34, 35).

With the crypt smaller than 10 mm, the healed rate was 80%, compared with 53% for teeth with larger crypts. Small crypts are usually enlarged with surgical drills to facilitate access for root-end management, creating an excisional wound within the bone (36) that is likely to enhance healing. In teeth with large crypts, also suggested by large diameter in the preoperative radiographs, expansion of the crypt is not needed, and healing might be compromised by the absence of an excisional wound (13). Crypt size is an intraoperative variable, but it was shown to be significantly associated (analysis not shown) with the preoperative lesion diameter, identified as an outcome predictor in the Phases 1 and 2 study (13). Therefore, in spite of the lost significance of the preoperative lesion diameter in the pooled study sample (Table 4), clinicians would do well to consider this specific variable to qualify the prognosis for patients considering apical surgery.

The healed rate in patients older than 45 years was 84%, compared with 68% for younger patients. Although a similar pattern was reported in a previous study (37), age was not found to be an outcome predictor in several other studies (9, 10, 13, 16). Further investigation of this variable and its biologic basis appears to be warranted.

Four additional variables (perforation, second-time surgery, root-filling depth, and restoration at follow-up) had nonsignificant healed rate differentials of 10% or larger. Of these, second-time surgery was previously suggested to have a poorer prognosis than first-time surgery (14, 38). Although a 21% difference in the healed rate was observed in the present study in favor of first-time surgery, the absence of significance suggested that this variable should be investigated with greater statistical power. Thus, investigation with a larger sample is indicated to clarify the prognostic value of this variable and the 3 others listed above.

In summary, 99 of 134 teeth (74%) were healed 4–10 years after apical surgery was performed with current techniques at a university graduate clinic. The prognosis of apical surgery was suggested to be significantly better for teeth with inadequate (too short or too long) preoperative root-filling length, for patients older than 45 years, and for teeth with crypt size smaller than 10 mm in diameter. Further research aiming to amass a critical sample of more than 600 teeth is warranted to investigate additional outcome predictors with adequate power.

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