A prospective cohort study of endodontic treatments of 1,369 root canals: results after 5 years

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Objective. The purpose of this prospective study was: 1) to follow-up a large number of endodontic treatments performed by a single operator, periodically checked over a 5-year period; and 2) to correlate outcome to a number of clinical variables.
Study design. This prospective study included all consecutive cases during the selected time period. All cases were followed regularly for a 5-year period. At the 5-year end point of the study, 470 patients with 816 treated teeth and with 1,369 treated root canals were available for evaluation.
Results. The overall rate of success among the 816 teeth/1,369 root canals available for evaluation was 88.6%/90.3%. The success rate for 435 teeth/793 root canals undergoing vital pulp therapy was 91.5%/93.1%. Teeth/root canals with necrotic pulp but without detectable periapical bone lesion were successfully treated in 89.5%/92.3%. If the pulp necrosis was complicated by apical periodontitis, the success rate fell to 82.7% for the teeth and 84.1% for the root canals ($P = .037$). Teeth with periapical lesion <5 mm had a success rate of 86.6%, and in cases where the lesion was ≥5 mm the rate of success was 78.2%.
Conclusions. More severe disease conditions negatively affects outcome. An optimal working length was identified. Excess of root canal filling material decreases success. Infected pulp space should be treated with an effective intracanal dressing. The quality of the coronal restoration or the placement of intracanal post retentions does not affect treatment outcome. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:825-842)**

Outcome of endodontic treatment has been the subject of many studies. Although some prognosis studies of endodontically treated teeth were conducted in the first half of the last century[1-6] the first comprehensive follow-up study was published by Strindberg in 1956.[7] In that study, performed on 775 endodontically treated roots—some radiographically followed for up to 10 years—he suggested a model for prospective clinical/radiologic cohort prognosis studies. A number of factors influencing the result of endodontic therapy were defined. Some of the most meaningful factors were the presence of resorbing apical periodontitis and the apical limit of the root canal filling.

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That study model has since been used as a model for a number of outcome studies. Presently, it is widely accepted that one of the most important factors influencing the outcome of endodontic treatment is the preoperative status of the pulp space, including the presence or absence of a radiographically detectable periapical bone lesion.[8-19] It was generally observed that teeth, where the pulp was vital, had a higher rate of successful treatment than when the disease of the pulp tissue had progressed and resulted in an apical periodontitis. Some studies also reported findings where an increased radiographic size of the periapical lesion had a negative effect on the treatment outcome.[10,12,15,18] Other studies, however, do not support that concept.[7,16] Studies with longer observation periods have reported that the preoperative size of the lesions had little influence on the outcome of endodontic treatment, because larger periapical lesions tend to heal at a slower rate.[7] In later studies, the microbiologic status of the pulp space has been added to the list of important outcome factors.[8-19]

Although the results of many of these well designed and executed outcome studies provide consistent information to guide good patient care, there is still much disagreement on treatment protocols, often based on little or no documented evidence. Examples of such

factors of disagreement are the effect of preoperative apical periodontitis and the need for comprehensive pulp space disinfection, including working area asepsis. Optimal working length is also intensively debated.

Since Strindberg's classical outcome study,[7] there has been no sufficiently powered randomized prospective comprehensive study published of endodontic treatment outcome based on contemporary treatment principles. There are a few, often cited, outcome studies focusing on the issue of single- or multivisit treatment of teeth with apical periodontitis.[20-23] Those studies are, however, underpowered and poorly randomized. Unfortunately, they are repeatedly used in systematic reviews and attempts to undertake meta-analysis,[24,25] resulting in spurious information.[26]

Lacking valid and relevant randomized controlled prospective clinical studies on endodontic treatment outcome, there is, however, substantial information to be gleaned from several prospective cohort studies published during the past 50 years.[7,10,14,16,27-31] The clinical work in many of those studies is, however, done by multiple operators or at trainee levels. The only cohort study executed by 1 single trained operator is now >55 years old.[7] Many instruments, materials, and treatment procedures have changed since the 1940s, and there is a need for additional information on a controlled large patient material.

The purpose of the present prospective study was: 1) to follow a large number of endodontic treatments performed by a single operator, periodically checked over a 5-year period; and 2) to correlate outcome to a number of clinical variables.

MATERIALS AND METHODS

Patient material

All patients received conventional therapeutic endodontic treatment by a general dentist with special interest in endodontics. The cases were consecutive during the selected time period. All treated cases were followed for postoperative development. For the study reported here, all patients that were followed regularly and had a 5-year follow-up visit were included. This group comprised a total of 780 patients who fulfilled the inclusion criteria. At the 5-year end point of the study, 470 patients with 816 treated teeth and with 1,369 treated root canals were available for evaluation. All treatment was provided by 1 operator (D.R.) using a standardized treatment protocol. Consent to treat was obtained from each of the patients in the study.

Treatment procedures

All clinical signs and symptoms, such as spontaneous or provoked pain, swelling, presence of sinus tract, and tenderness to percussion and palpation, were recorded. The periodontal condition of the tooth (mobility, gingival pocket depths) and the presence of carious lesions and/or previous restorations also were recorded. At least 1 diagnostic radiogram was exposed and a diagnosis established. The pulp diagnosis of "vital" or "necrotic" was made on the basis of the observation of continuous blood-filled pulp tissue in the root canal orifice(s), regardless of the clinical appearance of the tissue contained in the pulp chamber.

All endodontic treatments were performed using a strict aseptic technique. The tooth was first scaled with ultrasound and/or curettes, followed by plaque removal from the tooth/root surface with pumice and rubber cups. Restorations in connection with the access opening were removed. After rubber dam isolation, the treatment field (tooth, rubber dam, and clamp) was disinfected with 30% H_2O_2 and 5% tincture of iodine.[32]

Working length was established at the apical constriction with the help of an electronic apex locator and confirmed with radiographs. An effort was made to machine an "apical box" to snugly hold a gutta-percha master cone of appropriate size. After an adequate preflaring of the coronal two-thirds of the root canal with Gates-Glidden burs and hand instruments (Hedström files), the apical third was instrumented by hand instruments (Hedström and Kerr files) using the "step-back" technique. Irrigation was frequently made using copious amounts of 1% sodium hypochlorite with a minimum-size needle (NaviTip; Ultradent, South Jordan, UT, USA). No other chemical treatment of the root canals was attempted.

The treatments were normally completed in 2 visits. However, in 38% of the teeth with vital pulp and in 18% of teeth with necrotic pulp and no apical periodontitis, the treatment was completed in 1 treatment sequence.

An intracanal antimicrobial dressing was placed in teeth undergoing multivisit treatment. Slurry of calcium hydroxide, applied with a Lentulo spiral, was used in most cases. In some cases, instead of the calcium hydroxide, a small amount of metacresylacetate (Cresatina; Ogna, Muggiò, Italy), applied on a cotton pellet, was deposited in the pulp chamber. In a few cases, iodoform (Pasta Iodoformica Radiopaca; Ogna) was applied.

The root canals were filled with laterally compacted gutta-percha and a sealer. Different sealers, such as AH26 (De Trey Frères, Zürich, Switzerland), Bioseal (Ogna), Pulp Canal Sealer (Sybron Dental, Orange, CA, USA), Tubliseal (Sybron Dental), Apexit (Ivoclar Vivadent, Schaan, Lichtenstein), Mynol (Hygienic, Akron, OH, USA), and Endomethasone (Septodont, Saint-Maur-des-Fossés, France), were used randomly.

All treatment information was entered into a database at the time of treatment. Such data included age and gender, tooth number, number of roots and root canals, instrumentation and working length, preoperative pulp and periapical status, medicaments used, and their application time. Finally, the root canal sealer used was recorded.

After completion of the endodontic treatment, an appropriate restoration was placed.

Clinical and radiographic examination

The teeth in the study were followed regularly for 5 years. At each follow-up visit the patient was requested to report any symptoms, spontaneous or provoked. A careful inspection of the mucogingival fold was performed to exclude sinus tracts. To investigate the presence of provokable symptoms, lingual/palatal and buccal apical palpation and lateral/vertical percussion were done of the treated and neighboring teeth. In cases with clinical spontaneous or provoked symptoms (e.g., swelling, pain, and sinus tracts) being present, the case was classified as a failure, regardless of the presence of a normal radiographic appearance.

At each follow-up occasion, $\geq$1 radiogram in orthoradial view was exposed. Additional radiograms in eccentric view were exposed in cases with $>$1 root canal in the same root, when the canals could not be separated. Radiographic examination was performed using the long-cone technique (Explor-X 65 kV; Fiad, Trezzano, Italy) with Kodak Ultraspeed film 31 $\times$ 41 (DF 58) or 22 $\times$ 35 (DF 54; Eastman Kodak Company, Rochester, NY, USA) in a film holder (Rinn Corp., Elgin, IL, USA). The radiographs were processed manually in a darkroom following the recommendation of the manufacturer.

Evaluation of restoration quality and post placement

The quality of restoration at the time of final evaluation was assessed clinically and on the periapical radiograms. Restorations with good marginal adaptation (direct and indirect restorations) with no signs of recurrent caries were assessed as "good." Evidence of lost marginal adaptation, signs of decay involving dentin and/or enamel, or cases where the coronal restoration was lost were classified as "poor." This information was only used when calculating outcome with the tooth as a unit.

Roots in which a post was placed were recorded. This information was used only when calculating outcome with the root as a unit.

Outcome evaluation

The endodontic treatment results, including radiographs were evaluated by 2 independent examiners (J.R. and M.R.), who are both endodontic specialists with $>$30 years of clinical experience each. The evaluators had no information available about the treatment when reviewing the radiograms. The findings were grouped into successful, unsuccessful, and doubtful outcome. This grouping was discussed before beginning the evaluation process. The observers were calibrated similarly to Halse and Molven.[33] The radiographs were studied using a viewing box and a dental magnifying ($\times$2) viewer[34] designed to eliminate extraneous light. In cases of disagreement, the 2 observers discussed the cases to reach a consensus.

Rigid criteria, based on both clinical and radiographic examinations, were used in the evaluation of treatments, consisting of a slight modification of Strindberg's criteria.[7]

Successful: No signs or symptoms present on follow-up examination. Complete resolution of the lesion with redevelopment of a continuous lamina dura and a normal-appearing periodontal membrane space around the entire root perimeter.

Doubtful: No signs or symptoms present on follow-up examination and the initial radiographic lesion has decreased considerably in size, but normal periapical conditions are not still established at the end of the 5-year period. Periodontal ligament space may be widened around excess filling material.

Unsuccessful: Signs or symptoms present on follow-up examination. Periapical bone lesion may be present; the initial radiographic lesion has stayed the same size or increased in size; or the initial radiographic lesion has decreased in size, but complete healing has not been achieved at the end of the 5-year period.

These criteria were applied to each root canal treated. When evaluating multirooted teeth, the root canal with the worst outcome became the outcome of the tooth. In roots with multiple root canals, individual root canals were not analyzed separately.

In evaluating periapical lesions, the size was calculated, in mm, as the mean of the largest diameter and the perpendicular measurement.

Statistics

Measures. The outcome measure was dichotomized for use as the dependent measure in a logistic regression model. There were 15 predictor variables considered for use in the regression model, 10 of which were dichotomous: gender, maxillary vs. mandibular, apex diagnosis (periapical lesion vs. no lesion), medicament versus no medicament, pulp diagnosis (vital pulp vs. necrotic pulp or previously root filled canal), tooth type (single root vs. multiple roots), sinus tract (observed vs. not observed), pretreatment pain versus none, restora-

tion quality, and post placement. Three variables were continuous: age, weeks of medication, and fill level. Finally, 2 variables were analyzed as a trichotomous predictor: morphologic tooth type (incisor, premolar, or molar) and medicament type (calcium hydroxide, iodoform, or Cresatin). Three of the predictor variables are confounded a priori by design: Vital roots occur only when no sinus tract is observed and only when no periapical lesion is observed, and sinus tract can only occur simultaneously with a periapical lesion.

Statistical analyses. Separate simple logistic regressions were carried out for each of the 15 predictors, each assessing the relationship of the predictor with the single dichotomous outcome (success vs. failure). A sequential logistic regression model was then used to assess outcome as a function of the collective of independent measures. A main effects model was run first to establish a robust model without interactions, with the order of the 12 predictors in 7 sequential blocks: 1) gender; 2) age; 3) maxillary versus mandibular; incisor, premolar, or molar; and canal; 4) pulp diagnosis, apex diagnosis, and sinus tract observed; 5) fill level; 6) pain; and 7) weeks of medicament and medicament type. The exclusion of each of the 3 confounded predictors in block 4 did not alter the results. In addition, separate subgroup analyses were carried out within each of the 2 levels of the 3 confounded variables in block 4; none of these analyses produced results different from the analysis of all 816 teeth (for the tooth database) nor of all 1,369 roots (for the root database). Finally, a model that also included all 2-way interactions was assessed.

RESULTS

Of the 780 patients, 470 (60.3%) were available for the 5-year evaluation. This included 816 teeth, of which 435 teeth initially were diagnosed as having vital pulp. There were 1,369 treated root canals available for evaluation. Of the 310 patients not observed at the 5-year follow-up examination, 86 had moved out of the area and 31 were reported to have died. Of the other 193 patients, 131 were followed for 4 years but did not return to the 5-year visit owing to lack of time or being unreachable. Sixty-two teeth were lost earlier owing to reasons unrelated to endodontic outcome: 29 had vertical fractures, 22 nonrestorable recurrent caries, and 11 were extracted for unknown reasons. The overall results are summarized in Table IA.

The overall rate of success among the 816 teeth available for evaluation was 88.6%, with 10.9% failures and 0.5% doubtful. Calculated by the 1,369 root canals, 90.3% were successful, with 9.3% failures and 0.4% doubtful (Table IA).

The success rate for 435 teeth undergoing vital pulp therapy was 91.5%. For the 793 root canals with vital pulp, the success rate was 93.1% (Table IB).

Teeth with necrotic pulp but without detectable periapical bone lesion were successfully treated in 89.5%. The success rate for the root canals was 92.3% (Table IC). If the pulp necrosis was complicated by apical periodontitis, the success rate fell to 82.7% for the tooth and 84.1% for the root canals. These differences are statistically significant for the root canals ($P = .037$). Teeth with periapical lesion <5 mm had a success rate of 86.6%, and the cases where the lesion was ≥5 mm the rate of success was 79.4% ($P > .05$; Table II). The corresponding numbers for root canals were 87.5% and 80.9%, respectively ($P > .05$). There was a significant difference between periapical lesions ≥5 mm and all other cases with a necrotic pulp ($P = .0114$).

Teeth undergoing retreatment had a success rate of 90.5%. The failures in this group, however, were entirely clustered in the cases with apical periodontitis, which were successful in 83.3% (Table II). Teeth without apical periodontitis undergoing retreatment were 100% successful. There was a statistically significant difference ($P < .05$) in outcome between retreatment cases with and without apical periodontitis.

Tooth data

Descriptive statistics for all predictor variables as well as the outcome variable are presented in Table III. The intercorrelation matrix of the predictor variables showed that, in addition to necrosis, sinus tract, and periapical lesion being confounded a priori, other predictors were significantly correlated, some at large effect-size levels, e.g., medicament presence was, as would be expected, significantly confounded with medicament weeks ($r = .61$; $P < .001$), and some at medium effect-size levels: Medicament presence was significantly associated with canal ($r = .25$; $P < .001$) and with pulp diagnosis ($r = .22$; $P < .001$); fill level with pulp diagnosis ($r = .21$; $P < .001$); and pain presence with maxillary versus mandibular ($r = .20$; $P < .001$) and with medication weeks ($r = .20$; $P < .001$). Therefore, the use of the sequential analysis of predictor variables allowed the more proximal predictors to be assessed earlier for their association with outcome.

Table IV presents the percentages and sample sizes of success versus failure as a function of each of the predictors. The results of the simple logistic regression models for each of the predictors are shown in Tables IV and V. As can be seen, 4 of the predictors (incisor vs. premolar and premolar vs. molar, pulp diagnosis, apex diagnosis, and fill level) were significantly associated with outcome, and 2 showed a trend toward

Table IA. Outcome results tabulated for the complete study material studied

	Teeth				*Root canals*			
	Total		*Successful*	*Uncertain*	*Total*		*Successful*	*Uncertain*
	n	%	%	%	*n*	%	%	%
Gender								
Female	499	58.7	88.2	0.6	804	58.7	89.7	0.5
Male	317	41.3	89.3	0.3	565	41.3	91.2	0.2
Total	816		88.6	0.5	1,369		90.3	0.4
Tooth type								
Max. incisor	314	38.5	87	0.6	314	22.9	87	0.6
Max. premolar	138	16.9	92	0.7	238	17.4	92.9	0
Max. molar	68	8.3	91.2	0	234	17.1	94.9	0
Mand. incisor	27	3.3	96.3	0	31	2.3	96.8	0
Mand. premolar	129	15.8	93.8	0.8	136	9.9	93.4	1.5
Mand. molar	140	17.2	81.4	0	416	30.4	87.3	0.2
Diagnosis								
Vital pulp	435	53.3	91.5	0.2	793	57.9	93.1	0.1
Necrotic pulp	310	38	84.2	1	462	33.7	85.9	0.9
Previous fill	71	8.7	90.1	0	114	8.3	88.6	0
Apical diagnosis								
No lesion	531	65.1	91.7	0.6	939	68.6	93.3	0.3
<5 mm	152	18.6	86.8	0.7	232	16.9	87.9	0.9
>5 mm	133	16.3	78.2	0	198	14.5	78.8	0
First-visit pain								
Yes	375	46	87.5	0.5	691	50.5	89	0.4
No	441	54	89.6	0.4	678	49.5	91.6	0.3
Fill level								
Overfill					99	7.2	83.9	2
Flush with apex					134	9.8	83.6	0.7
≤0.5 mm					170	12.4	90	0
>0.5 to ≤1 mm					366	26.7	89.6	0.6
>1 to ≤1.5 mm					368	26.7	95.7	0
>1.5 to ≤2 mm					181	13.2	92.8	0
>2 to ≤2.5 mm					31	2.3	90.3	0
>2.5 to ≤3 mm					12	0.9	66.7	0
>3 mm					8	0.6	50	0

significance (age and sinus tract observed). Premolars showed significantly higher likelihood of success (93.6%) than both incisor (88.2%; $P = .027$), and molar (84.6%; $P = .002$), respectively. Teeth with a vital pulp diagnosis showed significantly higher likelihood of success (91.7%) than those with nonvital (86.0%; $P = .010$). Teeth with no lesions showed significantly higher likelihood of success (92.2%) than those with lesions (83.1%; $P < .001$). There was a significantly higher likelihood of success the higher the fill level ($P = .018$). Finally, there was a significant curvilinear effect for fill level ($P = .001$), such that those with fill levels in the center of the distribution (i.e., from 0 to 2.5 mm) showed significantly higher likelihoods of success than both those that were <0 mm as well as those >2.5 mm, the peak likelihood (95.9%) being fill levels from 1.00 to 1.50 mm. The trends indicated a linear effect of age: The older the patient, the higher the likelihood of success ($P = .051$). Finally, those teeth without a sinus tract were somewhat more likely to be associated with success (89.6%) than those with a sinus tract (80.4%; $P = .059$).

When analyzed as a group in the sequential multiple logistic regression, none of the 2-way interactions were seen to produce any significant moderator effects and were therefore removed from the model. The sequential multiple logistic regression showed, however, that only 3 predictors showed significance (premolar vs. molar, apex diagnosis, and the curvilinear effects of fill level), and only 2 showed a trend toward significance (incisor vs. molar and medicament category) (Table VI). Premolars showed significantly higher likelihood of success (93.6%) than molars (84.6%; $P = .002$), and a trend toward significance was evident for higher likelihoods of success for incisors (88.2%) than for molars (84.6%; $P = .053$).

Root canal data

Descriptive statistics for all predictor variables as well as the outcome variable are shown in Tables IA-IC, II, and

Table IB. Outcome results tabulated for teeth with vital pulp

	Teeth				*Root canals*			
	Total		*Successful*	*Uncertain*	*Total*		*Successful*	*Uncertain*
	n	%	%	%	*n*	%	%	%
Gender								
Female	258	59.3	90.7	0	450	56.7	92.2	0
Male	177	40.7	92.7	0.5	343	43.3	94.2	0.3
Total	435		91.5	0.2	793		93.1	0.1
Tooth type								
Max. incisor	128	29.4	89.8	0	128	16.1	89.8	0.6
Max. premolar	90	20.7	95.6	0	155	19.6	92.9	0
Max. molar	46	10.6	93.5	0	153	19.3	94.9	0
Mand. incisor	11	2.5	100	0	11	1.4	96.8	0
Mand. premolar	67	15.4	94	1.5	70	8.8	93.4	1.5
Mand. molar	93	21.4	86	0	276	34.8	87.3	0.2
First-visit pain								
Yes	228	52.4	90.4	0.4	442	55.7	91.9	0.2
No	207	47.6	92.8	0	351	44.3	94.6	0
Fill level								
Overfill					34	4.3	91.2	0
Flush with apex					69	8.7	82.6	1.4
≤0.5 mm					85	10.7	91.8	0
>0.5 to ≤1 mm					203	25.6	92.1	0
>1 to ≤1.5 mm					240	30.3	96.7	0
>1.5 to ≤2 mm					129	16.3	95.3	0
>2 to ≤2.5 mm					21	2.6	100	0
>2.5 to ≤3 mm					9	1.1	88.9	0
>3 mm					3	0.4	33.3	0

VII. The intercorrelation matrix of the predictor variables showed that, in addition to vital root canals, sinus tract, and lesion being confounded a priori, other predictors were significantly correlated, some at large effect-size levels, e.g., medicament presence was, as would be expected, significantly confounded with medicament weeks ($r = .57$; $P < .001$), and some at medium effect-size levels, e.g., medicament presence was significantly associated with canal ($r = .28$; $P < .001$). Therefore, the use of the sequential analysis of predictor variables allowed the more proximal predictors to be assessed earlier for their association with outcome.

Table VIII shows the percentages and sample sizes of success versus failure as a function of each of the predictors. The results of the simple logistic regression models for each of the predictors are presented in Table IX. As can be seen, 5 of the predictors (age, incisor vs. premolar, pulp diagnosis, apex diagnosis, sinus tract observed, and fill level [curvilinear]) were significantly associated with outcome, and one showed a trend toward significance (premolar vs. molar). Premolars showed significantly higher likelihood of success (93.5%) than incisors (88.3%; $P = .016$). Root canals with a vital pulp diagnosis showed significantly higher likelihood of success (93.2%) than those with nonvital (87.1%; $P < .001$). Root canals with no lesions showed significantly higher likelihood of success (93.6%) than those with lesions (84.1%; $P < .001$). Although there was no significant linear fill level effect, there was a significant curvilinear effect for fill level ($P < .001$), such that those with fill levels in the center of the distribution (i.e., from 0 to 2.5 mm) showed significantly higher likelihoods of success than both those that were <0 mm as well as those >2.5 mm, the peak likelihood (95.7%) being fill levels from 1.00 to 1.50 mm. The trends indicated that premolars showed somewhat higher likelihood of success (93.5%) than molars (90.1%; $P = .064$). The trend for the linear effect of age showed that the older the patient, the higher the likelihood of success ($P = .013$). Finally, those root canals without a sinus tract were somewhat more likely to be associated with success (91.2%) than those with a sinus tract (78.5%), $P = .001$.

When analyzed as a group in the sequential multiple logistic regression, none of the 2-way interactions were seen to produce any significant moderator effects and were therefore removed from the model. The sequential multiple logistic regression, however, showed only 3 predictors as being significant (apex diagnosis, pain level, and the curvilinear effects of fill level) and only 2 as showing a trend toward significance (age, and

Table IC. Outcome results tabulated for teeth with necrotic pulp

	Teeth				*Root canalst*			
	Total		*Successful*	*Uncertain*	*Total*		*Successful*	*Uncertain*
	n	%	%	%	*n*	%	%	%
Gender								
Female	194	62.6	84	1.5	290	62.8	85.2	1.4
Male	116	37.4	84.5	0	172	37.2	87.2	0
Total	310		84.2	1	462		85.9	0.9
Tooth type								
Max. incisor	150	48.4	83.3	0	150	32.5	83.4	1.3
Max. premolar	37	11.9	83.8	2.7	63	13.6	84.1	1.6
Max. molar	18	5.8	88.9	0	66	14.3	92.4	1.6
Mand. incisor	15	4.8	93.3	0	18	3.9	88.9	0
Mand. premol	52	16.8	92.3	0	56	12.1	94.6	0
Mand. molar	38	12.3	71.1	0	109	23.6	81.7	0
First-visit pain								
Yes	137	44.2	82.5	0.7	232	50.2	83.6	0.9
No	173	55.8	85.5	1.2	230	49.8	88.3	0.9
Fill level								
Periapical lesion								
Overfill					53	14.8	79.2	0
Flush with apex					44	12.3	84.1	0
≤0.5 mm					46	12.8	87	0
>0.5 to ≤1 mm					94	26.2	84	1.6
>1 to ≤1.5 mm					83	23.1	91.6	0
>1.5 to ≤2 mm					33	9.2	78.8	0
>2 to ≤2.5 mm					5	1.4	40	0
>2.5 to ≤3 mm					0	0	0	0
>3 mm					1	0	0	0
Total	243	78.4	82.7	0.4	359		84.1	0.3
No periapical lesion								
Overfill					10	9.7	80	20
Flush with apex					13	12.6	76.9	0
≤0.5 mm					20	19.4	95	0
>0.5 to ≤1 mm					31	30.1	93.5	0
>1 to ≤1.5 mm					20	19.4	100	0
>1.5 to ≤2 mm					5	4.9	100	0
>2 ≤ 2.5 mm					2	1.9	100	0
>2.5 to ≤3 mm					0	0	0	0
>3 mm					2	1.9	100	0
Total	67	21.6	89.5	3.0	103		92.3	1.9

incisor vs. premolar; Table X). Root canals with no lesions showed significantly higher likelihood of success (93.6%) than those with lesions (84.1%; $P < .001$). There was a significant curvilinear effect for fill level ($P < .001$), such that those with fill levels in the center of the distribution (i.e., from 0 to 2.5 mm) showed significantly higher likelihoods of success than those both <0 mm and >2.5 mm, the peak likelihood (95.9%) being fill levels from 1.00 to 1.50 mm (Tables X and XI). Though not significant as a univariate predictor, pain status proved significant in the multiple regression, such that root canals of those without pain showed a significantly higher likelihood of success (91.9%) than root canals of those with pain (89.4%; $P = .049$). Finally, there was a trend for premolars showing somewhat higher likelihood of success (93.5%) than incisors (88.3%; $P = .076$; Table VIII).

Restorations and posts

Restoration quality had no significant effect on outcome, regardless of treatment diagnosis ($P = .94$; Table XII). The overall success rate for good quality was 88.9% versus poor quality at 89.2%.

Similarly, the placement of a post in a root canal did not alter the treatment outcome in general ($P = .13$). The overall success rate for post was 92.7% versus no post at 89.9%. There was, however, a significant improvement in treatment outcome when posts were placed after endodontic treatment of teeth with vital pulp (96.4%) versus no post placement (91.9%; Table XIII).

Table II. Distribution of outcome data delineated by diagnostic combinations

	Teeth		*Root canals*	
Diagnosis	*Total, n*	*Successful, %*	*Total, n*	*Successful, %*
Vital pulp	435	91.5	793	93.1
Necrosis—no lesion	67	89.5	103	92.3
Necrosis w/lesion	243	82.7	359	84.1
Necrosis w/large lesion, >5 mm	124	79	183	80.9
Necrosis w/small lesion, <5 mm	119	86.6	176	87.5
Retreatment—no lesion	29	100	43	100
Retreatment w/lesion	42	83.3	71	81.7
Retreatment w/large lesion, >5 mm	9	67.7	15	53.3
Retreatment w/small lesion, <5 mm	33	87.9	56	89.3
Nec + ReTx—no lesion	96	92.7	146	94.5
Nec + ReTx w/lesion	285	82.8	430	83.7
Nec + ReTx w/large lesion, >5 mm	133	78.2	198	78.8
Nec + ReTx w/small lesion, <5 mm	148	89.2	232	87.9
		P value		
Necrosis w/lesion/no lesion		.1744		.0369
Necrosis w/small/large/no lesion		.1094		.0222
Necrosis—no lesion/small lesion		.5510		.2181
Necrosis—no lesion/large lesion		.0665		.0099
Necrosis—small/large lesion		.1211		.0859
ReTx w/lesion/no lesion		.0206		.0029
ReTx w/small/large/no lesion		.0104		.0001
ReTx—no lesion/small lesion		.0639		.0268
ReTx—no lesion/large lesion		.0012		.0001
ReTx—small/large lesion		.0999		.0014
Nec + ReTx w/lesion/no lesion		.0178		.001
Nec + ReTx w/small/large/no lesion		.0029		.0001
Necrosis + ReTx—small/large lesion		.0121		.0105

For the tooth the diagnosis and the outcome was determined by the most diseased root canal.
Nec, Necrosis; *ReTx*, retreatment.

Table III. Sample sizes and percentages for dichotomous measures with the tooth as the unit

Variable	*n*	*%*
Successful outcome	723	89.0%
Male	316	38.9%
Maxillary	517	63.7%
Tooth type		
Incisor	339	41.9%
Premolar	265	32.6%
Molar	208	25.6%
Single root canal	498	61.3%
Vital pulp diagnosis	434	53.4%
Apex diagnosis-lesion	284	35.0%
Sinus tract observed	46	5.7%
Pain	373	45.9%
Medicament	585	72.0%
Medicament type		
None	227	28.0%
$CaOH_2$	429	52.8%
Iodoform	12	1.5%
Cresatin	144	17.7%
Poor restoration	130	16.0%

Total sample is 816 teeth. Four uncertain cases were excluded.

DISCUSSION

The material in this study has been divided into tooth as a unit and root canal as a unit. This allows for a more detailed analysis of the various factors modifying treatment outcome. An analysis based on the tooth as a unit is relevant for teeth with only 1 root canal. However, the outcome of a multirooted/multiple-canal tooth is entirely dependent on the treatment result of one of the roots/canals. Therefore, the chances for a successful treatment result will always be lower than when considered for the individual root canal. In addition, the analysis of the influence of individual treatment factors will be less clear when analyzing the results based on tooth observations.

Gender

The study material was heavily weighted toward female subjects. Only 41% of the teeth/roots were from male subjects. There was, however, no difference in overall outcome between the male and female groups (Table IA). This finding is in line with an earlier systematic review of literature on this topic.[35]

Table IV. Percentages and sample sizes [n (%)] of success versus failure as a function of each predictor variable for teeth, from their respective simple logistic regressions

	*Success**	*Failure**	*Total†*	*P value*
Overall	89.0% (723)	11.0% (89)	100.0% (812)	<.001
Gender				.71
Male	89.6% (283)	10.4% (33)	38.9% (316)	
Female	88.7% (440)	11.3% (56)	61.1% (496)	
Age (y)				.051
<10	80.0% (4)	20.0% (1)	0.6% (5)	
11-20	88.3% (143)	11.7% (19)	20.0% (162)	
21-30	87.6% (219)	12.4% (31)	30.8% (250)	
31-40	86.0% (154)	14.0% (25)	22.0% (17)	
41-50	94.8% (109)	5.2% (6)	14.2% (125)	
51-60	92.3% (60)	7.7% (5)	8.0% (65)	
61-70	94.1% (32)	5.9% (2)	4.2% (34)	
>70	100.0% (2)	0.0% (0)	0.2% (2)	
Jaw				
Maxillary	89.4% (462)	10.6% (65)	63.7% (517)	
Mandibular	88.5% (261)	11.5% (34)	36.3% (295)	
Tooth type				.008
Incisor	88.2% (299)	11.8% (40)	41.7% (339)	
Premolar	93.6% (248)	6.4% (17)	32.6% (265)	
Molar	84.6% (176)	15.4% (32)	25.6% (208)	
Tooth morphology				.20
Single root	90.2% (449)	9.8% (49)	61.3% (498)	
Multiple root	87.3% (274)	12.7% (40)	38.7% (314)	
Pulp diagnosis				.010
Vital	91.7% (398)	8.3% (36)	53.4% (434)	
Not vital	86.0% (325)	14.0% (53)	46.6% (378)	
Apex diagnosis—lesion				<.001
Lesion	83.1% (236)	16.9% (48)	35.0% (284)	
No lesion	92.2% (487)	7.8% (41)	65.0% (528)	
Sinus tract observed				.059
Present	80.4% (37)	19.6% (9)	5.7% (46)	
Absent	89.6% (686)	10.4% (80)	94.3% (766)	
Fill level (mm)				
Linear				.018
Curvilinear				.001
<0	79.7% (47)	20.3% (12)	7.3% (59)	
0 (flush)	82.4% (70)	17.6% (15)	10.5% (85)	
0.0-0.5	88.5% (92)	11.5% (12)	12.8% (104)	
0.5-1.0	88.1% (192)	11.9% (26)	26.8% (218)	
1.0-1.5	95.9% (211)	4.1% (9)	27.1% (220)	
1.5-2.0	90.6% (87)	9.4% (9)	11.8% (96)	
2.0-2.5	89.5% (17)	10.5% (2)	2.3% (19)	
2.5-3.0	66.7% (4)	33.3% (2)	0.7% (6)	
>3.0	60.0% (3)	40.0% (2)	0.6% (5)	
Pain				.35
Pain	87.9% (328)	12.1% (45)	45.9% (373)	
No Pain	90.0% (394)	10.0% (44)	54.1% (439)	
Weeks of medicament				.54
0	88.1% (200)	11.9% (27)	28.0% (227)	
1	90.5% (305)	9.5% (32)	41.5% (337)	
2	88.2% (90)	11.8% (12)	12.6% (102)	
3	88.9% (48)	11.1% (6)	6.7% (54)	
4	93.3% (28)	6.7% (2)	3.7% (30)	
>4	83.9% (52)	16.1% (10)	7.6% (62)	
Medicament type				.80
None	88.1% (200)	11.9% (27)	28.0% (227)	
$CaOH_2$	90.0% (386)	10.0% (43)	52.8% (429)	
Iodoform	91.7% (11)	8.3% (1)	1.5% (12)	
Cresatin	87.5% (126)	12.5% (18)	17.7% (144)	

Table IV. Continued

	*Success**	*Failure**	*Total*†	*P value*
Restoration quality				.94
Good	88.9 (606)	11.1 (78)	84.0% (682)	
Poor	89.2 (116)	10.8 (14)	16.0% (130)	

Four uncertain cases were excluded from calculation.
*Row percentage.
†Column percentage.

Table V. Simple logistic regression for teeth: outcome measure likelihood as a function of each predictor variable

							95% CI for Exp(B)	
Predictor variable	*B*	*SE*	*Wald*	*df*	*P value*	*Exp(B)*	*Lower*	*Upper*
Gender	0.09	0.23	0.14	1	.71	1.09	0.69	1.72
Age	0.17	0.09	3.79	1	.051	1.18	1.00	1.40
Maxillary	0.09	0.23	0.15	1	.70	1.09	0.70	1.72
Incisor, premolar, molar			9.59	2	.008			
Incisor vs. premolar	0.67	0.30	4.90	1	.027	1.95	1.08	3.53
Incisor vs. molar	−0.31	0.26	1.44	1	.23	0.74	0.45	1.21
Premolar versus molar	−0.98	0.32	9.54	1	.002	0.38	0.20	0.70
Canal	−0.29	0.23	1.65	1	.20	0.75	0.48	1.17
Pulp diagnosis	0.59	0.23	6.65	1	.010	1.80	1.15	2.82
Apex diagnosis—lesion	−0.88	0.23	15.10	1	<.001	0.41	0.27	0.65
Sinus tract observed	0.74	0.39	3.55	1	.059	2.09	0.97	4.48
Fill level (linear)	0.33	0.14	5.64	1	.018	1.39	1.06	1.83
Fill level (curvilinear)	−0.28	0.08	11.38	1	.001	0.75	0.64	0.89
Pain	−0.21	0.23	0.86	1	.35	0.81	0.52	1.26
Weeks of medicament	−0.05	0.08	0.37	1	.54	0.96	0.82	1.11
Medicament type			1.02	3	.80			
None vs. any	−0.18	0.42	0.18	1	.67	0.84	0.37	1.89
$CaOH_2$ vs. iodoform	0.20	1.06	0.04	1	.85	1.23	0.15	9.72
$CaOH_2$ vs. cresatin	−0.25	0.30	0.69	1	.41	0.78	0.43	1.40
Iodoform vs. cresatin	−0.45	1.07	0.18	1	.67	0.64	0.08	5.23

Table VI. Multiple logistic regression for teeth: outcome measure likelihood as a function of resultant significant predictor variables

							95% CI for Exp(B)	
Predictor variable	*B*	*SE*	*Wald*	*df*	*P value*	*Exp(B)*	*Lower*	*Upper*
Intercept	2.68	0.18	218.34	1	<.001	14.58		
Incisor, premolar, molar			10.20	2	.06			
Incisor vs. premolar	0.49	0.31	2.55	1	.11	1.64	0.89	3.00
Incisor vs. molar	−0.52	0.27	3.74	1	.053	0.60	0.35	1.01
Premolar vs. molar	−1.01	0.32	9.90	1	.002	0.36	0.19	0.68
Apex diagnosis—lesion	−0.86	0.24	13.20	1	<.001	0.42	0.27	0.67
Fill level (curvilinear)	−0.25	0.09	8.62	1	.003	0.78	0.65	0.92

Age

In general, successful treatment outcome increased with age (Table XIV). Out of 521 teeth on patients <40 years old, 454 were successful (87.1%), and of 293 teeth on patients >40 years old, 268 were successful (91.8%). This difference is significant when evaluated by the tooth ($P = .044$) or by the root canal ($P = .022$). This difference becomes greater if the age cutoff is set at 50 years. The lower age group had a successful outcome of 87.7%, and patients >50 years old experienced a 94.6% rate of success ($P = .023$ by tooth and $P = .002$ by root). When analyzed as a group in the sequential multiple logistic regression, only a tendency of a better treatment result was noticed when consid-

Table VII. Sample size and percentages for dichotomous measures for root canal

Variable	*n*	*%*
Successful outcome	1236	90.3%
Male	565	41.3%
Maxillary	786	57.4%
Tooth type		
Incisor	345	25.2%
Premolar	374	27.3%
Molar	650	47.5%
Single root canal	507	37.0%
Vital pulp diagnosis	793	57.9%
Apex diagnosis—lesion	430	31.4%
Sinus tract observed	65	4.7%
Pain at start of treatment	691	50.5%
Medicament	1068	78.2%
Medicament type		
None	298	21.8%
$CaOH_2$	794	58.1%
Iodoform	15	1.1%
Cresatin	259	19.0%
Post placed	356	26.0%

Total sample is 1,369 root canals.

ering age ($P = .55$; Table X). This effect of age on outcome was somewhat surprising, because earlier studies have no or an opposite effect of age.[7,36]

Tooth type

In the overall material, maxillary incisors (87%) and mandibular molars (81.4%) had the lowest rates of treatment success. These low rates of healing are similar in teeth with necrotic pulp, where the outcome expectation for mandibular molars (71.1%) and maxillary incisors (83.3%) is especially poor.[7] Mandibular incisors had the overall highest rate of success. However, the numbers available for study were low. For teeth with vital pulp, mandibular and maxillary premolars and maxillary molars had high rates of success (94%, 95.6%, and 93.5%, respectively). There was a significant difference in favorable outcome between mandibular and maxillary molar roots (87.3% vs. 94.9%; $P = .0019$) and maxillary incisors and maxillary molars (87% and 94.9%; $P = .0019$). These numbers were only slightly modified by diagnosis. The information about the difficulty to successfully treat maxillary incisors is not new but it reinforces the concept that the maxillary incisor requires special attention.[7] The high rate of failure when treating mandibular molars has been reported earlier on materials treated by different providers.[37,38] The high rate of failures on mandibular molars may be associated with the complex anatomy, making the mesial root difficult to debride.[39]

Pulpal and periapical diagnosis

The importance of early diagnosis of endodontic diseases to enhance a favorable treatment outcome is illustrated by our results when the teeth/root canals were dichotomized by disease conditions. Thus, treatment of teeth with vital pulp had a better result than after pulp necrosis has developed. Pulp space infection adds further complications. Thus, the presence of apical periodontitis is a serious complication impeding the chances for successful endodontic treatment.[19] This observation is well demonstrated in Table II. These observations further strengthen earlier studies reporting the deleterious effect of periradicular inflammations.[10,36,40] Strindberg[7] is often cited as documentation that the success rate of teeth with vital pulp may be lower than for teeth with necrotic pulp. However, the treatment protocol for vital pulp in the study by Strindberg[7] is significantly different from contemporary technique and therefore not helpful as a reference. It may be concluded from the present study that the most important factor for increasing favorable endodontic treatment outcome is early diagnosis followed by aggressive treatment. Because more complex pathologic conditions are the result of pulp space infection, it is logical to suggest that such aggressive treatment includes antiseptic regimens as well as treatment asepsis. This is well in line with earlier findings from smaller controlled studies.[10,16,19,41]

There were only 46 cases where sinus tracts were observed at the time of treatment. These teeth and roots had about double the rate of treatment failures compared with uncomplicated apical periodontitis (simple logistic regressions: $P = .001$.) However, this factor fails to stand out after a multiple logistic regression analysis.

Pain at time of first presentation for treatment had a surprisingly strong effect, reaching significance ($P = .049$) when analyzed by multiple logistic regression. The symptoms at presentation may be a sign of a more severe disease condition. Postoperative pain was very unusual and therefore not analyzed.

Medication

The appropriateness of intracanal dressing for endodontic treatment to enhance the infection control during treatment has been intensively debated, and only limited and poorly controlled evidence has been available.[20,23-25] Recent systematic reviews, based on underpowered studies, suggest that there is no difference in long-term outcome between treatments completed in one treatment session compared with when intracanal dressing is used over 2 sessions.[35,42] In contrast, we found a significant difference in outcome when treating teeth with necrotic pulp with or without intracanal

Table VIII. Percentages and sample size [% (n)] of success versus failure for root canals as a function of each predictor variable, from their respective simple logistic regressions

	*Success**	*Failure**	*Total†*	*P value*
Overall	90.6% (1,236)	9.4% (128)	100.0% (1,364)	<.001
Gender				.45
Male	91.3% (515)	8.7% (49)	41.3% (564)	
Female	90.1% (921)	9.9% (79)	58.7% (800)	
Age (y)				.013
<10	85.7% (6)	14.3% (1)	0.5% (7)	
11-20	89.5% (280)	10.5% (33)	22.9% (313)	
21-30	89.9% (346)	10.1% (39)	28.2% (385)	
31-40	87.7% (271)	12.3% (38)	22.7% (309)	
41-50	95.0% (191)	5.0% (10)	14.7% (201)	
51-60	94.8% (92)	5.2% (5)	7.1% (97)	
61-70	96.0% (48)	4.0% (2)	3.7% (50)	
>70	100.0% (2)	0.0% (0)	0.1% (2)	
Jaw				
Maxilla	91.3% (714)	8.7% (68)	57.3% (782)	
Mandible	89.7% (522)	10.3% (60)	36.3% (295)	
Tooth type				.052
Incisor	88.3% (303)	11.7% (40)	25.1% (343)	
Premolar	93.5% (348)	6.5% (24)	27.3% (372)	
Molar	90.1% (585)	9.9% (64)	47.6% (649)	
Tooth morphology				.74
Single root	90.3% (455)	9.7% (49)	37.0% (504)	
Multiple roots	90.8% (781)	9.2% (90)	63.0% (860)	
Pulp diagnosis				<.001
Vital	93.2% (738)	6.8% (54)	58.1% (792)	
Not vital	87.1% (498)	12.9% (74)	41.9% (572)	
Apical diagnosis				<.001
Lesion	84.1% (360)	15.9% (68)	31.4% (428)	
No lesion	93.6% (876)	6.4% (60)	68.6% (936)	
Sinus tract				.001
Present	78.5% (51)	21.5% (14)	4.8% (65)	
Absent	91.2% (1185)	8.8% (114)	95.2% (1299)	
Fill level (mm)				
Linear				.010
Curvilinear				<.001
Excess	85.6% (83)	14.4% (14)	7.1% (97)	
Flush	84.2% (112)	15.8% (21)	9.8% (133)	
0-0.5	90.0% (153)	10.0% (17)	12.5% (170)	
0.5-1.0	90.1% (328)	9.9% (36)	26.7% (364)	
1.0-1.5	95.7% (352)	4.3% (16)	27.0% (368)	
1.5-2.0	92.8% (168)	7.2% (13)	13.3% (381)	
2.0-2.5	90.3% (28)	9.7% (3)	2.3% (31)	
2.5-3.0	66.7% (8)	33.3% (4)	0.9% (12)	
>3	50.0% (4)	50.0% (4)	0.6% (8)	
Pain on presentation				.12
Pain	89.4% (615)	10.6% (73)	50.4% (688)	
No pain	91.9% (621)	8.1% (55)	49.6% (676)	
Time of medication (wk)				.27
None	88.8% (262)	11.2% (33)	21.7% (295)	
1	92.1% (535)	7.9% (46)	42.7% (581)	
2	92.4% (170)	7.6% (14)	13.5% (184)	
3	89.8% (106)	10.2% (12)	8.7% (118)	
4	92.2% (59)	7.8% (5)	4.7% (64)	
>4	84.9% (101)	15.1% (18)	8.7% (119)	
Type of medication				.35
None	88.8% (262)	11.2% (33)	21.7% (295)	
$Ca(OH)_2$	91.8% (727)	8.2% (65)	52.8% (792)	
Iodoform	86.7% (13)	13.3% (2)	1.1% (15)	
Cresatin	89.2% (231)	10.8% (28)	19.0% (259)	

Table VIII. Continued

	*Success**	*Failure**	*Total†*	*P value*
Post placement				
Post	92.7% (328)	7.3% (26)	26.0% (354)	
No post	89.9% (908)	10.1% (102)	74.0% (1010)	

Five uncertain cases were excluded from the calculations.
*Row percentage.
†Column percentage.

Table IX. Simple logistic regressions for root canals: outcome measure likelihood as a function of each predictor variable

							95% CI for Exp(B)	
Predictor variable	*B*	*SE*	*Wald*	*df*	*P value*	*Exp(B)*	*Lower*	*Upper*
Gender	0.14	0.19	0.55	1	.46	1.15	0.79	1.67
Age	0.18	0.07	6.14	1	.013	1.20	1.04	1.38
Maxillary	0.19	0.19	1.02	1	.31	1.21	0.84	1.74
Incisor, premolar, molar			5.91	2	.052			
Incisor vs. premolar	0.65	0.27	5.79	1	.016	1.91	1.13	3.25
Incisor vs. molar	0.19	0.21	0.77	1	.38	1.21	0.79	1.83
Premolar vs. molar	−0.46	0.25	3.44	1	.064	0.63	0.39	1.03
Canal	0.63	0.19	0.11	1	.74	1.07	0.73	1.55
Pulp diagnosis	0.71	0.19	14.18	1	<.001	2.03	1.41	2.94
Apex diagnosis—lesion	−1.01	0.19	29.16	1	<.001	0.36	0.25	0.52
Sinus tract observed	1.05	0.32	10.92	1	.001	2.85	1.53	5.31
Fill level (linear)	0.19	0.12	2.65	1	.10	1.21	0.96	1.51
Fill level (curvilinear)	−0.29	0.07	18.05	1	<.001	0.75	0.66	0.86
Pain	−0.29	0.19	2.44	1	.12	0.75	0.52	1.08
Weeks of medicament	−0.07	0.06	1.20	1	.27	0.94	0.83	1.05
Medicament type			3.28	3	.35			
None vs. any	−0.06	0.32	0.04	1	.85	0.94	0.50	1.77
$CaOH_2$ vs. iodoform	−0.54	0.77	0.50	1	.48	0.58	0.13	2.63
$CaOH_2$ vs. cresatin	−0.30	0.24	1.63	1	.20	0.74	0.46	1.18
Iodoform vs. cresatin	0.24	0.79	0.09	1	.76	1.27	0.27	5.92

Table X. Multiple logistic regressions for root canals: outcome measure likelihood as a function of resultant significant predictor variables

							95% CI for Exp(B)	
Predictor variable	*B*	*SE*	*Wald*	*df*	*P value*	*Exp(B)*	*Lower*	*Upper*
Intercept	2.74	0.27	101.51	1	<.001	15.53		
Age	0.14	0.07	3.69	1	.055	1.15	1.00	1.33
Incisor, premolar, molar			3.52	2	.17			
Incisor vs. premolar	0.50	0.28	3.15	1	.076	1.65	0.95	2.87
Incisor vs. molar	0.09	0.23	0.17	1	.68	1.10	0.70	1.72
Premolar vs. molar	−0.41	0.25	2.57	1	.11	0.67	0.41	1.09
Apex diagnosis-lesion	−0.95	0.20	23.41	1	<.001	0.39	0.26	0.57
Fill level (curvilinear)	−0.26	0.07	13.68	1	<.001	0.77	0.67	0.86
Pain	−0.39	0.20	3.89	1	.049	0.68	0.46	1.00

dressing. In the present study 3 different antimicrobial materials were used, $Ca(OH)_2$ slurry, Cresatin deposit, and iodoform. The latter was used very infrequently and was therefore not analyzed. It was noted that Cresatin is a relatively ineffective intracanal antiseptic (Table XVA). There was no significant enhancement of treatment outcome when using Cresatin as an intracanal dressing compared with using no intracanal dressing

Table XI. Treatment outcome after endodontic treatment organized by the level of root filling material in the root canal, with root canal as the unit

	Vital pulp		*Necrotic pulp*		*Retreatment*	
Fill level	*Total, n*	*Successful, %*	*Total, n*	*Successful, %*	*Total, n*	*Successful, %*
Excess	34	91.2	63	79.4	2	100
Flush	69	82.6	57	82.5	8	100
0.0-0.5 mm	85	91.8	66	89.4	19	84.2
0.5-1.0 mm	203	92.6	125	86.4	38	86.8
1.0-1.5 mm	240	96.7	103	93.2	25	96
1.5-2.0 mm	129	95.3	38	81.6	14	100
2.0-2.5 mm	21	100	7	57.1	3	100
2.5-3.0 mm	9	88.9	0	0	3	0
>3 mm	3	33.3	3	66.7	2	50

Data reported by original diagnosis.

Table XII. Effect of restoration quality, with tooth as the unit

		Successful		*Total*
	Quality	*n*	*%*	*n*
All teeth (incl. previous fill)	Good	606	88.9	682
	Poor	116	89.2	130
Vital pulp	Good	332	91.5	363
	Poor	66	93	71
Necrosis with and without lesion	Good	231	86.2	268
	Poor	40	81.6	49
Necrosis, no lesion	Good	60	92.3	65
	Poor	10	100	10
Necrosis, all lesions	Good	171	84.2	203
	Poor	30	76.9	39
Necrosis, lesion <5 mm	Good	84	88.4	95
	Poor	19	82.6	23
Necrosis, lesion >5 mm	Good	87	80.6	108
	Poor	11	68.8	16

The results are reported by pretreatment diagnosis of the pulp tissue. Five-year observation. Four uncertain cases were excluded.

Table XIII. Effect of post placement, with root canal as the unit

	Successful		
	n	*%*	*Total*
All roots			
Post	328	92.7	354
No post	908	89.9	1010
Vital pulp			
Post	214	96.4	222
No post	523	91.9	569
Necrosis; with and without lesion			
Post	78	84.8	92
No post	319	87.2	366
Necrosis, no lesion			
Post	15	100	15
No post	81	93.1	87
Necrosis, all lesions			
Post	64	82.1	78
No post	238	85.3	279
Necrosis, lesion <5 mm			
Post	39	88.6	44
No post	115	88.5	130
Necrosis, lesion >5 mm			
Post	25	73.5	34
No post	123	82.6	149

The results are reported by pretreatment diagnosis of the root canal pulp tissue. Five-year observation. Five uncertain cases were excluded.

and completing the treatment in 1 session ($P = .32$). When treating teeth with necrotic pulp, however, there is a significant outcome gain when using $Ca(OH)_2$ slurry as an intracanal dressing compared with a single-visit treatment protocol with no pulp-space antiseptic dressing ($P = .002$).[43,44]

The use of intracanal antimicrobial dressing when treating teeth with a vital pulp provides little gain over a single-session treatment protocol (Table XVB). It is interesting to note that extending the dressing time beyond 2 weeks results in a significant loss of treatment result (Table XVI). This may be due to an increased risk for pulp space reinfection with time owing to failure of the temporary restoration.[45]

Root canal filling

Seven different root canal sealers were used in the study. There was no specific protocol for the selection of sealer for individual cases; they were applied in a random fashion. When studying the outcome, it is obvious that AH26, Bioseal, Mynol, and Apexit are clustered at a higher rate of success than Pulp Canal Sealer, Endomethasone, and Tubliseal (Table XVII). The outcomes for these 2 groups of sealers were significantly different ($P = .0004$), reflecting their tissue-irritating potential.[46]

Strindberg[7] stated that the highest success rate is obtained when the root filling is confined to 1 mm from the radiographic apex. Subsequently, most prognosis

Table XIV. Treatment outcome of endodontic treatment 5 years after completion, arranged by age group

	Teeth			*Root canals*		
Age range, y	*Total, n*	*Successful, %*		*Total, n*	*Successful, %*	
0-10	3	66.7		7	85.7	
11-20	81	88.9		165	89.7	
21-30	207	87.4		332	89.2	
31-40	233	85.4		394	88.1	
41-50	164	89		272	90.1	
51-60	79	93.7		124	96	
61-70	33	93.9		46	95.7	
>70	17	100		29	100	
Total	817	88.4		1,369	90.1	
0-40	521	87.1	$P = .0441$	894	89.1	$P = .0221$
>40	293	91.8		470	93	
0-50	684	87.7	$P = .0235$	1,170	89.1	$P = .0018$
>50	129	94.6		199	96.5	

Table XVA. Treatment of root canals with necrotic pulp

	Total		*Successful*	
Medicament	*n*	*%*	*n*	*%*
All $Ca(OH)_2$, multivisit	288	62.3	259	89.9
All cresatin, multivisit	82	17.7	68	82.9
No dressing, one visit	77	16.7	59	76.6
$Ca(OH)_2$ vs. no dressing			$P = .002$	
Cresatin vs. no dressing			$P = .32$	
$Ca(OH)_2$ vs. Cresatin			$P = .0808$	
$Ca(OH)_2$ + Cresatin vs. no dressing			$P = .0063$	

Effect of various treatment protocols using $Ca(OH)_2$ slurry or Cresatin on a cotton pellet as intravisit dressing. In some cases the treatment was completed in 1 session. Iodoform was used in 15 cases not reported here.

Table XVB. Treatment of root canals with vital pulp

		Successful	
Medicament	*Total, n*	*n*	*%*
All $Ca(OH)_2$, multivisit	415	391	94.2
All Cresatin, multivisit	169	155	91.7
No dressing, single-visit	207	190	91.8

There was no statistically significant difference in treatment outcome due to various intravisit dressing protocols.

Table XVI. Treatment of root canals with vital pulp with calcium hydroxide dressing

		Successful	
$Ca(OH)_2$ time, wk	*n*	*n*	*%*
1	221	212	95.9
2	53	51	96.2
3	63	59	93.7
4	29	26	89.7
>4	49	43	87.8
All cases with $Ca(OH)_2$	415	391	94.2
1 wk + 2 wk vs. 3 wk + 4 wk + >4 wk		$P = .0314$	
1 wk vs. 4 wk + >4 wk		$P = .0172$	

Outcome after various time of dressing. Extended dressing time (>2 wk) lowers the rate of successful treatment. More than 2 weeks' time of intracanal dressing results in a significant lowering of successful treatment outcome.

Table XVII. Outcome of endodontic treatment using various endodontic sealers

			Successful (canals)	
	Teeth	*Canals*	*n*	*%*
A. AH26	90	233	215	92.3
B. Bioseal	176	273	254	93
C. Mynol	31	58	54	93.1
D. Apexit	107	202	189	93.6
E. Pulp canal sealer	270	378	329	87
F. Endomethasone	101	165	145	87.9
G. Tubliseal	34	47	41	87.2
Total	816	1,369	1,234	90.5
			$P = .048$	
A, B, C, D			$P = .9630$	
E, F, G			$P = .9639$	
A, B, C, D vs. E, F, G			$P = .0004$	

studies confirmed the practice of staying short of the apex to obtain the best treatment outcome.[16-19,47-49] Those earlier observations are strongly supported by the findings in the present study. The level where the root canal filling material was placed (working length) had a strong influence on treatment outcome. Thus, both for cases with vital pulp and for cases with necrotic pulp, a successful treatment outcome is less likely when working at the radiographic apex or overfilling the root canal. This effect appears to be less clear when analyzing retreatment case (Table XI).

For teeth with vital pulp, the optimal working length appears to be 1-2 mm short of the radiographic apex of the tooth. Comparing the outcome for teeth with the

Table XVIII. Retreatment of previously treated root canals

Apical diagnosis	Total, n	Successful	
		n	%
A. no PA lesion	43	43	100
B. <5 mm	56	50	89.3
C. >5 mm	15	8	53.3
		$P < .0001$	
A vs. B		$P < .0001$	
A vs. B+C		$P < .0001$	
A vs. C		$P < .0001$	
B vs. C		$P = .0014$	

There was a statistically significant lower rate of treatment success when apical periodontitis has developed. A larger lesion (>5 mm) has a lower success rate than when a smaller lesion (<5 mm) is present.

root canal filling reaching beyond 1 mm short of apex with root canal fillings placed within 1-2 mm of the apex, the difference is 88.3% versus 94.9% ($P = .0032$).

For teeth with necrotic pulp, the optimal working length appears to be 0.5 to 1.5 mm short of the radiographic apex of the tooth. Comparing the outcome for teeth with the root canal filling reaching beyond 0.5 mm short of apex with root canal fillings placed within 0.5-1.5 mm of the apex, the difference is 80% versus 89% ($P = .0243$).

For teeth undergoing retreatment, the material was relatively small and no obvious trend could be detected related to fill levels (Table XI). When analyzed as a group in the sequential multiple logistic regression, fill level is highly significant as analyzed in both linear ($P = .01$) and curvilinear ($P < .001$) modes.

There is, in our opinion, no one absolute and obvious reason why fill level becomes significantly important for treatment outcome. The etiology is most likely multifactorial. However, there are some observations from microbiology and histopathology which may provide possible explanations. Although most root canal filling materials become less irritating with time, many materials are, in their freshly prepared form, highly toxic and may initially cause tissue necrosis in the proximity of the excess material.[50] This necrotic tissue will support growth of microorganisms, if present. A long-term outcome study by Engström et al.[10] supports this hypothesis. In association with excess root canal filling materials those authors observed a failure rate of 9.7% when bacteriologic cultures were negative at the time of root filling; when the culture was positive, the failure rate was quadrupled (41.4%).

It is unlikely that overinstrumentation was involved in the excess of sealers in this study. However, it is worthwhile to note the findings by Bergenholtz et al.[51] in an outcome study of retreatment cases. They observed a very significant increased failure rate when the root canal was instrumented beyond the apical foramen or overfilled. We observed similar effects (Table XVIII). This suggests that the root canal files in some instances may have implanted infectious material from the root canal into the lacerated periapical tissues.

The instrumentation in this treatment material was always attempted within the apical constriction. When excess of root canal sealer is forced beyond the apical constriction, the wall of the apical funnel-like cementum extension of the root canal was not sufficiently instrumented. Therefore, the extruded toxic sealer had incomplete adaptation to the root canal walls, creating localized areas of tissue injuries, including necrosis. Bacterial growth could occur there with limited infection defense. However, if that area is undisturbed by foreign materials, the tissue reorganization in the apical area may proceed unimpeded, allowing the normal immune defense mechanisms to be effective.

Recently suggestions have been raised that conventional radiograms are unreliable for the assessment of working/fill levels. Cone-beam computerized tomographic (CBCT) scans are suggested as more reliable in assessing the true anatomic location, even if not completely infallible.[52] That finding, however, is irrelevant for the present study, because the only observation used here was the relationship to the radiographic apex of the tooth studied. We make no claim for the true anatomic working level, because that continues to be difficult to establish. Conventional image technique will be important for the foreseeable future. Most practitioners will not have CBCT scans readily available in the near future, and its use continues to be limited by radiation and cost concerns. This result clearly supports earlier findings from smaller outcome studies and verifies the earlier observations as established facts beyond further discussion.[7]

Restoration and posts

The quality of the restoration did not significantly influence the treatment outcome, regardless of pretreatment pulp diagnosis. This is in contrast to several earlier reports of cross-sectional studies where the quality of the restoration has been given significant importance to the endodontic treatment outcome.[53,54] Such studies have no detailed information available related to the endodontic treatments nor the restorations. In a recent attempt to review and perform a meta-analysis of limited published data, the importance of the restoration was also given some significance.[55] The endodontic treatment is often severely compromised in these

cross-sectional studies assessing the clinical value of the restoration for the outcome of the endodontic treatment. Therefore, these studies are less valuable for the understanding of the importance of the restoration for the outcome of well executed endodontic treatment.

The sample size in the present study was large and provides controlled temporal information. The findings provide a unique opportunity to conclude that the quality of the restoration has insignificant effect on the long-term outcome of endodontic treatment. This observation concurs with an earlier report from a controlled study.[56] It may also be concluded that post placement does not impair periapical tissue healing after endodontic treatment. This observation concurs with an earlier report.[53]

CONCLUSIONS

This prospective outcome study of a large number of endodontically treated teeth allows us to make the following observations:

1. Treatment outcome is dependent on the diagnosis at presentation. The more severe disease conditions are the more difficult to treat successfully.
2. There is an optimal level for placement of the root canal filling. Excess of root canal filling material decreases the rate of successful treatment.
3. Teeth with infected pulp space should be treated in $\geq$2 treatment sessions using an effective intracanal dressing to optimize treatment outcome.
4. Intracanal dressing will not enhance the treatment outcome for vital pulp treatment.
5. Successful treatment outcome increases with the patient's age.
6. The quality of the coronal restoration does not affect the endodontic treatment outcome.
7. Post placement does not negatively affect the rate of success of endodontically treated roots.
8. Mandibular molars are the most difficult teeth to treat successfully.

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