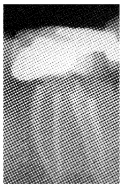

CLINICAL ARTICLE

An analysis of endodontic treatment with three nickel-titanium rotary root canal preparation techniques

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Abstract

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Aim To investigate clinical results of root canal treatment performed with the aid of nickel-titanium (NiTi) rotary instruments.

Summary A total of 179 patients underwent root canal treatment with either (A) Lightspeed, or (B) ProFile .04 or (C) ProFile .04 and .06 or GT rotary instruments to create tapered preparations. In groups A and B, laterally condensed gutta-percha and AH Plus were used. Canals in group C were obturated with System B, Obtura II and Roth's 801 sealer. Initial and recall radiographs were assessed using the periapical index (PAI). Outcomes were analysed using chi-square tests, event-time analyses and logistic regression models. Two hundred and thirty-three teeth were radiographically assessed after a mean interval of 25.4 ± 11.8 months. Favourable outcome of treatment, defined as PAI < 3 at recall was 86.7%. Logistic regression analysis and univariate analyses indicated that teeth with preoperative PAI scores >2 and retreated teeth had a significantly lower chance of healing compared with periapically healthy teeth and primary treatments, respectively. Preparation technique, length of fill and the type of sealer did not significantly affect healing rates.

Key learning points

- Root canal treatment with NiTi root canal instrumentation systems renders favourable outcomes in more than 86% of the cases.
- Outcome is significantly affected by preoperative diagnoses but not by the specific choice of instrumentation system.

Keywords: cohort study, healing, nickel-titanium, periapical index, rotary.

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Introduction

A key part of root canal treatment is canal instrumentation, which includes shaping root canals in a manner that allows rinsing with irrigation solutions, disinfection with medicaments and ultimately filling. Instrumentation alone within necrotic root canals has been shown to reduce the counts of intra-canal bacteria, yet disinfection remains an indispensable adjunct in order to reach the goal of elimination of infection (Byström & Sundqvist 1981). Nickel-titanium (NiTi) systems have been shown to allow preparation of root canals with less procedural errors, even by undergraduate dental students (Pettiette *et al.* 2001). However, a clinical study indicated that neither NiTi rotary nor step-back instrumentation techniques using stainless-steel hand K-files could predictably render canals free of bacteria (Shuping *et al.* 2000). Furthermore, these techniques were not significantly different in their ability to reduce intracanal bacteria when instrumentation was supplemented with sodium hypochlorite irrigation (Dalton *et al.* 1998). In addition, no significant differences in preparation outcomes were found between different NiTi systems when canals were instrumented (Short *et al.* 1997). Effective cleaning of root canals may also be influenced by the taper (Smith *et al.* 1993, Peters *et al.* 2003) or by the apical size of a preparation (Card *et al.* 2002).

Numerous *in vitro* studies have investigated properties of NiTi instruments, such as instrument defects, torque, apically directed force and centring ability in curved root canals. However, it is difficult to correlate these findings with a given clinical situation (Kirkevang & Hørsted-Bindslev 2002). Factors identified as influencing treatment outcomes included, amongst others, pulpal status, number of treatments, pre-existing periapical lesions, microbiological culture results, overfilling during obturation and leakage of the temporary or permanent coronal restoration (Basmadjian-Charles *et al.* 2002, Hoskinson *et al.* 2002, Chugal *et al.* 2003, Friedman *et al.* 2003). However, minimal information is available on differences in clinical outcomes of teeth treated endodontically with various NiTi rotary techniques.

The aim of the current study was to (i) assess clinical results obtained following root canal treatment performed using different NiTi rotary instruments, and (ii) investigate the influence of preoperative variables on these outcomes.

Materials and methods

Patients

From the patient population that visited the Dental School, University of Zurich, Switzerland, those who had received a root canal filling between 1997 and 1999 by two full-time faculty members, were scheduled for regular radiographic and clinical follow-up visits. The initial review occurred after 3 months and the final review after 3 years. Inclusion criteria were that (i) the treatment was performed with NiTi rotary instruments and (ii) consent was given to regular follow-up visits. Patient consent to study protocols was obtained prior to root canal treatment. Both clinicians involved had comparable experience of more than 3 years with rotary NiTi systems; they had extensive preclinical practice sessions with all instrument types used in this study.

Patients with a diagnosis of diabetes or an immunocompromising disease were excluded from the study. At recall, all patients had received definitive restorations. Treatment groups A–C were seen in sequence, i.e. patients visiting the clinic in the first year were allocated to group A, the following year protocol B was used and the final year patients were assigned to group C.

Endodontic treatment modalities

Preoperative radiographs (Digora; Soredex, Helsinki, Finland) were taken and endodontic diagnoses were established. Rubber dam was placed and operative sites were disinfected by swabbing with 1% NaOCl. Access cavities were prepared and optimized with the aid of an operating microscope (OPMI; Zeiss, Oberkochen, Germany). Canal orifices were located and canals were shaped with one of three preparation schemes: in group A, Lightspeed instruments (Lightspeed Inc., San Antonio, TX, USA) were used to create an apical stop, in group B, ProFile .04 instruments (Dentsply Maillefer, Ballaigues, Switzerland) were utilized to shape an apical stop while in group C either GT Rotary instruments (Dentsply Maillefer) or a combination of ProFile .04 and .06 instruments was used to achieve a tapered shape. Irrigation solutions (1–2.5% NaOCl and 17% EDTA) were delivered with a 27 gauge needle attached to a Luer Lock syringe.

Lightspeed instruments were used according to guidelines accepted by the manufacturer at that time. Specifically, an initial step down was performed using Gates Glidden drills of descending sizes to shape the coronal 4 mm of the canals. Then, the apical third of the canal was explored and working length determined using size 10 K-Flexofiles (Dentsply Maillefer). Canal lengths were estimated using an electronic apex locator (Root ZX, Morita, Tokyo, Japan) and the position of the file verified with radiographs. Working length in group A was canal length minus 1 mm. Apical preparation (minimum size corresponding to size 40) was then initiated with hand instruments up to a size 20 and continued with Lightspeed instruments. Finally, a step-back phase blended the apical preparation into the stepped down portion of the canal.

In group B, step-down preparation was completed in a similar manner and was followed by a crown-down with ProFile .04 instruments sizes 60, 45, 40 and 35 to reach two-thirds of the estimated working length. K-Flexofiles were used to establish working length and the apical shape to a size 20. Apical stops (minimum size 35) at canal length minus 1 mm were completed with ProFile instruments; a short step-back concluded the preparation.

In group C, step-down and crown-down were done as in group B, but a combination of ProFile .04 and .06 tapered instruments or in some cases GT Rotary instruments were used to create a continuously tapered shape. The apical extent of the preparation was canal length minus 0.5 mm and the minimum apical size was 20.

Root canal treatment in 56 cases with a diagnosis of an inflamed pulp was completed in the first appointment; in all other cases, including those with periapical lesions, canals were dried with paper points (Roeko, Langnau, Germany) and chairside-mixed $Ca(OH)_2$ was placed into the canals as an antibacterial dressing for at least 7 days. The teeth were then restored temporarily with Cavit and/or Ketac Fil (3M Espe, Rüschlikon, Switzerland).

At the filling appointment, canals were accessed and the intracanal medicament removed. Canals were irrigated with EDTA and a final rinse of NaOCl, then dried and filled. Lateral compaction of gutta-percha was completed in groups A and B, using AH Plus (Dentsply DeTrey, Konstanz, Germany) as the sealer. In group C, canals were obturated with a hybrid method using the System B heat source (SybronEndo, Orange, CA, USA), the Obtura II (Spartan Co., Fenton, MS, USA) device and Roth's 801 (Roth Inc., Chicago, IL, USA) as the sealer. Canal orifices were sealed with a resin-modified glass–ionomer (Vitrebond, Vivadent, Schaan, Liechtenstein) and the access cavities were temporarily restored. For definitive restorations, the patients were then returned to the referring dentists.

Radiographic technique and scoring

All patients were enrolled in a recall scheme and were scheduled for visits after approximately 3 months as well as 1, 2 and 3 years postoperatively. During these recall appointments, digital radiographs were taken, similar to the preoperative radiographs, with the aid of a film holder (Hawe Neos, Bioggio, Switzerland) and a long cone X-ray source (Heliodent, Siemens, München, Germany). The clinician, who had treated that patient previously, took the radiographs. The radiographs then were evaluated according to the criteria of Ørstavik (1991) and a periapical index (PAI) score was assigned to individual root apices.

PAI scores are defined as follows (Ørstavik 1996): PAI 1 was assigned to normal apical periodontium; PAI 2 referred to bone structural changes indicating, but not pathognomonic for, apical periodontitis; PAI 3 was given to cases with bone structural changes with some mineral loss characteristic of apical periodontitis; PAI 4 denoted a well defined radiolucency; PAI 5 indicated a lucency with radiating expansion of bone structural changes.

Two evaluators with over 10 years experience in radiographic diagnosis were calibrated using a standard set of reference radiographs and they independently evaluated all clinical radiographs. Preoperative radiographs and those at recall were evaluated at separate time-points. In case of disagreement, the case was jointly evaluated and an agreement reached. A subset of radiographs was assessed in duplicate and it was shown that intra-examiner reliability was good (Cohen's $\kappa = 0.76$) Clinical data pertaining to preoperative status (retreatment yes/no and sensibility to cold yes/no) were further noted and tabulated along with the length of the root filling in relation to the root apex. This parameter was measured with an endodontic ruler to the nearest 0.5 mm and initially stratified into three categories: longer than the radiographic apex, 0–2 mm within the radiographic apex, and less than 2 mm from the radiographic apex. For multi-rooted teeth, the root with the highest PAI score determined the overall score and the extension of the filling material was assigned accordingly.

Statistical analysis

As PAI scores represent noncontinuous data, nonparametric tests and descriptors were used to analyse and present the data. Data were tabulated, proportions and 95% confidence intervals (CI, Gardner *et al.* 2000) were calculated. Significance of univariate associations was assessed with chi-square tests. For a 'healthy/diseased' analysis, PAI data was dichotomized with PAI scores 1 and 2 indicating a 'healthy periapex' and scores from 3 to 5 describing diseased periapical tissues. Effect-time analyses and logistic regression models were used to analyse for associations between pre- and perioperative variables and treatment outcomes. The statistics packages StatView 4.5.1 (Abacus, Berkeley, CA, USA) and SPSS 9.0 (SPSS Inc., Chicago, IL, USA) were used.

Results

Table 1 illustrates the demographic distribution of patients enrolled in the study. Overall mean age was 41.9 ± 13.4 years with no differences between male and female patients.

Table 1 Age distribution of patients enrolled in the study ($n = 179$)

Age (years)	Males	Females	Total
11–30	15	18	33
31–50	43	54	97
51–70	21	23	44
71–90	2	3	5
Total	81	98	179

The populations treated in groups A–C were statistically similar with respect to mean age and distribution of teeth (Table 2) as was the initial distribution of PAI scores (Table 3). Of the 263 teeth included at the beginning of this study, 22 were excluded from the evaluation due to incomplete recall records and a further eight teeth were disqualified due to insufficient recall times (<3 months, overall recall rate 88.6%). Of the recalled teeth, 40 had an initial clinical diagnosis of irreversible pulpitis while 193 teeth did not give a response to pulp sensitivity tests. From the latter group of teeth, a total of 30, 73 and 90 were root filled with treatment regimes in groups A–C, respectively. PAI scores, as determined from pre-treatment radiographs, were equally distributed among the treatment groups ($P = 0.434$) and are listed in Table 3. Recall times were statistically similar among experimental groups A, B and C.

Patients were recalled and evaluated after 25.4 ± 11.8 months. Radiographically, overall favourable outcome of treatment or 'success', defined as a postoperative PAI score <3 at recall was 86.7% (CI: 82–91, Fig. 1). There were no significant differences ($P = 0.346$) between the regimes in group A (93.0%, CI: 81–98), group B (86.7%, CI: 78–92) and group C (84.0%, CI: 76–90) with respect to healing rates. Of the teeth with no periapical pathosis, indicated by initial PAI scores <3 ($n = 131$), 95.4% (CI: 90–98; light shade in Fig. 1) had a favourable outcome of treatment. Teeth with signs of periapical pathosis in the initial radiographs had a significantly lower healing rate (75.5%, CI: 66–83, $P < 0.001$, dark shade in Fig. 1). Table 4 details the fate of cases with respect to preoperative periapical status. An initial logistic regression model incorporating all cases indicated that only the periapical status (PAI < 3, compared with PAI > 2) and treatment timing (primary treatment compared with retreatment) contributed significantly to healing outcomes with odds ratios of 8.85 (CI: 3.3–23.7) and 4.75 (CI: 2.0–11.5), respectively. Furthermore, no significant factors could be determined in this model in univariate analyses due to low expected frequencies (i.e. area IV, Fig. 1). Consequently, the model was reduced to include only teeth with preoperative PAI > 2 (areas II and III in Fig. 1).

Univariate analyses for these 102 cases were performed for the factors 'retreatment', 'length of fill', 'obturation' and 'preparation'. Retreated cases had a significantly lower healing rate ($P < 0.01$, 61.2%, CI: 47–74) than cases of primary treatment (85.0%, CI: 75–92; Table 5). There was no significant association of length of fill stratified into three levels with radiologic outcomes. However, the number of cases filled shorter than 2 mm

Table 2 Distribution of tooth types into groups A, B and C ($n = 268$)

	Maxilla ($n = 167$)			Mandible ($n = 101$)		
	A	B	C	A	B	C
Incisors	5	5	17	1	1	4
Canines	2	3	5	2	2	1
Premolars	7	20	20	5	7	11
Molars	9	42	32	17	23	27
Total	23	70	74	25	33	43

Table 3 Distribution of initial PAI scores for recalled teeth into groups A, B and C ($n = 233$)

	A	B	C	Total
1	19	50	49	118
2	5	4	4	13
3	4	11	10	25
4	15	26	37	77
5	0	0	0	0

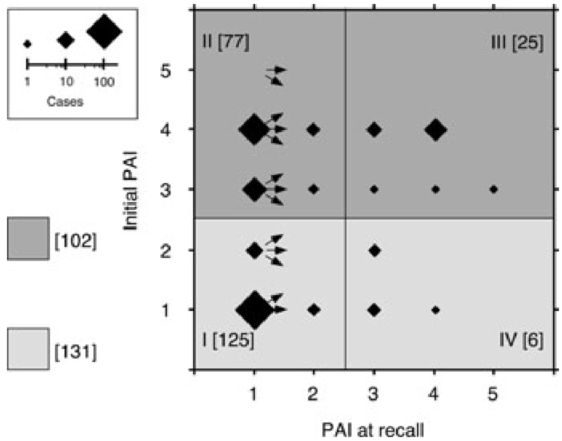

Figure 1 Association of initial PAI scores with postoperative scores. Figures in brackets indicate numbers of cases in each area. Symbol sizes indicate number of cases in each cell (see insert). Cases in areas I and II could stay in the same category, change their radiographic status after treatment towards improvement (lower PAI) or increased signs of apical pathosis (higher PAI) (note arrows with respect to initial diagnoses). Healing rate was 87.4% overall (202/233 cases), 95.4% for cases without apical pathosis initially (groups I and IV, light shade) and 75.5% for cases with initial PAI scores ranging from 3 to 5 (areas II and III, dark shade).

Table 4 Numbers of cases (percentages in parentheses) with differences in PAI scores at last recall compared with initial scores, split by preparation technique into groups A, B and C ($n = 233$)

	A	B	C	Total
−3	12 (27.9)	12 (13.3)	23 (23.0)	47
−2	3 (7.0)	10 (11.1)	11 (11.0)	24
−1	7 (16.3)	11 (12.2)	8 (8.0)	26
0	21 (48.8)	52 (57.8)	51 (51.0)	124
+1	0 (0.0)	3 (3.3)	4 (4.0)	7
+2	0 (0.0)	1 (1.1)	3 (3.0)	4
+3	0 (0.0)	1 (1.1)	0 (0.0)	1

Table 5 Univariate analyses for teeth with initial periapical pathosis ($n = 102$)

Variable	d.f.	χ^2	P
Retreatment	1	7.122	<0.01
Length of fill	2	1.534[a]	n.s.
Obturation	1	0.234	n.s.
Preparation	2	1.038[a]	n.s.

d.f., degree of freedom.
[a]Ambiguous result due to low expected frequencies.

of radiographic apex was low ($n = 4$). Furthermore, there was no significant association of preparation technique with outcomes (Table 5). Subsequent event-time analyses confirmed this result (data not shown). Univariate analyses then indicated that obturation techniques had no significant effect on healing rates. However, tapered preparation and thermoplastic obturation (group C) were associated with a significantly higher incidence of overfills ($P < 0.05$; 48.9%, CI: 35–63) than group B (16.7%, CI: 8–32).

Finally, a logistic regression model was constructed that included the following variables: 'retreatment' (two levels), 'length of fill' (reduced to two levels), 'preparation' (two dummy variables). Again, the only significant effect was 'retreatment' (Table 6).

Table 6 Logistic regression analysis for teeth with initial periapical pathosis ($n = 102$)

Variable	d.f.	β	SE	*P*	Odds ratio	CI
Retreatment	1	+1.307	0.490	0.008	3.69	1.4–9.6
Length of fill	1	+0.096	0.528	0.856	1.10	
Group A versus others	1	+0.721	0.766	0.346	2.06	
Group C versus others	1	−0.156	0.548	0.776	0.86	
Constant	1	+1.688	0.485	0.001		

d.f., degree of freedom. β is a coefficient representing the weighing of each variable in the logistic model. The sign indicates the direction of the effect, (−) designates decreased chances while (+) indicates a higher chance for healing. SE is the standard error of the coefficient β. Odds ratios (with 95% confidence interval, CI) measure the chance of healing in presence of a risk factor. An odds ratio of 1 indicates that the risk factor does not contribute to the chance of healing.

Retreated cases had an odds ratio of 3.69 (CI: 1.4–9.6), indicating a chance for healing that is increased by more than three times in a initial treatment compared with a retreatment case. However, the model predicted only 76% of the outcomes correctly. A reduced model, including only 'retreatment' did not change the predictive value.

Discussion

Since the advent of NiTi instruments over a decade ago numerous *in vitro* investigations have assessed various properties of these instruments. However, only limited information is available regarding clinical outcomes following root canal treatment that had been completed with the aid of NiTi rotary instruments. A two-part study that used a prospective cross-over design to compare root canal treatment rendered by undergraduate students (Pettiette *et al.* 1999) found that canal curves were better maintained with NiTi hand files compared with stainless steel K-files. Furthermore, they demonstrated a correlation between occurrences of preparation errors and delayed healing (Pettiette *et al.* 2001).

In general, endodontic outcomes have been of scientific interest for almost a century. Unfortunately, methodological problems greatly hamper comparisons between the existing body of evidence (Friedman 2002). For instance, cross-sectional studies spanning almost 30 years and populations suggest that proportions between 31 and 60% of endodontically treated teeth exhibit signs of periapical disease (Bergenholtz *et al.* 1973, Hülsmann *et al.* 1991, Kirkevang *et al.* 2001). This fact is at apparent variance with longitudinal studies that follow a specified patient population treated under controlled conditions; these studies indicate favourable outcome rates between 85 and 95% (Strindberg 1956, Hoskinson *et al.* 2002, Friedman *et al.* 2003). Recent epidemiological analyses identified many possible explanations for this phenomenon, most importantly varying definitions of 'success' and 'failure' and the factor 'observation time' (Weiger *et al.* 1998, Chugal *et al.* 2001, Kirkevang *et al.* 2001). Consequently, a meta-analysis of endodontic outcome studies appears problematic (Kojima *et al.* 2004).

In the present study, similar recall times existed among the experimental groups, beginning with an initial recall after 3 months. It may be argued that this recall time is too short to demonstrate resolution of a lesion, but it could be sufficient to demonstrate changes in PAI scores (Ørstavik 1996, Huumonen *et al.* 2003).

In the future, guidelines based on the CONSORT agreement (Newcombe 2004) should ensure that clinical trials in endodontics are planned and reported according to standards securing highest possible levels of evidence. This relates firstly to patient recruitment and allocation into groups. Required patient numbers should be calculated in order to avoid underpowered studies (Newcombe 2004) and a random process should be used for treatment specification. For the present study, no power calculation was done at the initiation of the research but instead all available patients were included and there was a high recall rate. Patients were randomly assigned to a treatment group but in theory the process could have been improved if patient selection into the treatment groups A–C had started simultaneously. However, not all instrumentation systems were immediately available and hence, the study design was adjusted accordingly.

Radiographic outcomes have been used previously to indicate 'success' and 'failure' of endodontic treatment and should be compared with clinical, i.e. nonradiographic evaluations (Ørstavik 1991). In the present study, only radiographic analyses were reported as all teeth were restored and fully in function.

Since Goldman *et al.* (1972) demonstrated poor inter- and intraobserver reliability in interpretation of periapical radiographs, attempts have been made to improve evaluation procedures (for review see Kirkevang & Hørsted-Bindslev 2002). In order to define a more reliable criterion for 'success' and 'failure', the present paper uses the PAI index (Brynolf 1967, Ørstavik 1991) to describe periapical tissues. While the PAI system does not eliminate examiner-derived subjectivity, improved receiver-operating-characteristic curves have been demonstrated (Ørstavik *et al.* 1986). As PAI data are nominal in nature, the present analysis relies on nonparametric statistical models and tries to incorporate as much original PAI data as possible as shown in Fig. 1. However, a dichotomization with a cut-off between PAI scores 2 and 3 was required to allow an analysis of treatment outcome and the term 'favourable outcome of treatment' was adopted for all cases that were assigned PAI scores of 1 and 2 at recall.

Some earlier investigations have included the root as the statistical unit (Chugal *et al.* 2001, Hoskinson *et al.* 2002); the present study utilized the tooth as the unit to avoid clustering effects as recommended previously (Ørstavik *et al.* 1986, Ørstavik 1991). To this end, conflicting results have been reported comparing 'success' rates using roots and teeth as the unit (Friedman 1998, Hoskinson *et al.* 2002).

Overall healing rates are similar to those described recently (Pettiette *et al.* 2001, Kirkevang & Hørsted-Bindslev 2002, Friedman *et al.* 2003, Kojima *et al.* 2004). Initial analyses of the present study material had indicated that the presence of a periapical lesion reduced the chance for healing significantly. This finding is in clear agreement with most previous reports (Strindberg 1956, Storms 1969, Sjögren *et al.* 1990, Basmadjian-Charles *et al.* 2002, Hoskinson *et al.* 2002, Friedman *et al.* 2003). The presence of a radiographically detectable lesion was highly correlated with a clinical diagnosis of an infected root canal (data not shown) and therefore only their preoperative periapical analysis was used in the primarily radiographic outcome analysis. A recent meta-analysis (Kojima *et al.* 2004) has reported 'success' rates of 82.8% for initially inflamed and 78.9% for infected teeth; these proportions were similar to those described in the present study for teeth with and without periapical lesions when retreatment cases were excluded.

In the present study, calcium hydroxide as an anti-bacterial dressing (Byström & Sundqvist 1981) was placed in all infected teeth, while 56 cases with inflamed pulps were treated in a single visit. Hence, rates of favourable outcome were not affected by this variable when focusing on infected teeth.

The analysis of teeth with initial PAI > 2 demonstrated that retreated cases had a lower healing rate compared with primary treatments. This result corroborates clinical and radiographic 'success/failure' data (Allen *et al.* 1989, Sjögren *et al.* 1990, Kvist & Reit 1999, Hoen & Pink 2002). The healing rate of retreated cases (61.2%) in the present material was similar to those in a recent report (Gorni & Gaglinai 2004). It should be noted, however, that the operators were faculty members and that in this particular setting practitioners tended to refer mostly difficult retreatment cases to the University Clinic.

In the final logistic regression model and in univariate analyses, all other explanatory variables, most notably the instrumentation system and the obturation procedures did not contribute significantly to healing rates. This finding is in keeping with a recent report comparing two treatment regimes that were similar to those used in the present study (Hoskinson *et al.* 2002) and may be explained by the absence of gross preparation errors. Those had been implicated earlier in reduced healing rates (Pettiette *et al.* 1999, 2001). Furthermore, the sample size in the present study might have been too small to detect significant effects in this regard.

Finally, the length of the filling material in relation to the radiographic apex did not significantly affect outcomes in the present study. This finding is at apparent variance with some reports (Sjögren *et al.* 1990, Kojima *et al.* 2004) but is similar to recent radiographic analyses (Hoskinson *et al.* 2002, Huumonen *et al.* 2003). It may be explained by the notion that infected dentine chips but not extruded sealer may be the reason for persisting infection with apparent overfilling (Yusuf 1982). However, the fate of a root filled tooth is not exclusively determined by healing rates. Considering the many confounding variables in outcome assessment, a multi-centred prospective study of treatment regimens is more than warranted.

Conclusions

Despite its limitations, the present study is one of the few reports on the clinical performance of NiTi rotary instruments in root canal treatment. Univariate tests and logistic regression analyses showed no significant differences in radiological outcomes comparing three preparation and two obturation schemes. Two preoperative variables, presence/absence of a periapical lesion and retreatment/initial treatment, showed significant effects.

Disclaimer

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