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Comparison of root canal preparation with two rotary NiTi instruments: ProFile .04 and GT Rotary

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Abstract

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Aim To compare root canal preparation using ProFile .04 and GT Rotary nickel–titanium instruments (both Dentsply Maillefer, Ballaigues, Switzerland).

Methodology Fifty extracted mandibular molars with mesial root canal curvatures between 20 and 40° were randomly divided into two groups and embedded in a muffle system. All root canals were prepared to size 45 using ProFile .04 or GT rotary instruments. The following parameters were evaluated: straightening of root canal curvature, postoperative root canal cross-section, cleaning ability, safety issues and working time.

Results Both NiTi systems maintained curvature well; the mean degree of straightening was <1°. The majority of the root canals prepared with ProFile .04 (80.8%) and GT (84.0%) postoperatively showed a round or oval cross-section. For debris, ProFile .04 and GT rotary achieved 67.1% and 71.6% scores of 1 and 2, respectively. Concerning the coronal region statistical analysis showed a better result for GT than for ProFile .04. For the middle and apical thirds of the root canals, results did not differ significantly. None of the two systems completely removed smear layer. Ten procedural incidents occurred with ProFile .04 compared with five with GT. Mean working time was shorter for ProFile .04 (131.8 s) than for GT (143.7 s); the difference was not significant.

Conclusions Both systems respected original root canal curvature well and were safe to use. Smear layer removal was not satisfactory with either systems.

Keywords: automated root canal preparation, canal aberration, GT Rotary, NiTi instruments, ProFile .04, working safety.

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Introduction

Rotary endodontic instruments fabricated from nickel–titanium alloy have shown to be helpful adjuncts for root canal preparation (Hülsmann *et al.* 2005). In the past few years, advanced instrument designs including noncutting tips, radial lands, different cross-sections and varying tapers have been developed to improve working safety, to shorten working time and to create a greater flare within the preparations (Bergmans *et al.* 2001).

Numerous studies have shown the ability of rotary nickel–titanium systems to maintain original root canal curvature and to complete preparations in an acceptable time (Hülsmann *et al.* 2005). Some investigations have reported that rotary NiTi instruments do not clean effectively root canal walls, in particular the apical part of curved canals (Hülsmann *et al.* 2001, 2003a, Versümer *et al.* 2002, Prati *et al.* 2004, Paqué *et al.* 2005). Additional concern has been expressed about the comparatively high incidence of fractures of rotary nickel–titanium instruments (Kavanagh & Lumley 1998).

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The purpose of the present study was to evaluate several parameters of automated root canal preparation using ProFile .04 and GT Rotary NiTi instruments (Dentsply Maillefer, Ballaigues, Switzerland) using the same study design as in previous reports (Hülsmann *et al.* 2001, Versümer *et al.* 2002, 2003a, Prati *et al.* 2004, Paqué *et al.* 2005), thus allowing the comparison of different NiTi systems.

The ProFile .04 instruments have a U-shaped cross-section, a noncutting safety tip, radial lands and a .04 taper. GT Rotary instruments have similar features except the original introduction pack comprised three types of instruments. The first four instruments are the GT Rotary instruments with a taper of 12%, 10%, 8% and 6% all having the same diametre of 0.20 mm. The second four instruments are the GT Rotary Files .04 having a 4% taper with a tip diametre ranging from size 20 to 35; these instruments are used for the preparation of the apical third and are identical to the ProFile .04 instruments. The final instruments are the GT Accessory Files with a 12% taper and tip diametres of 35, 50 and 70.

Materials and methods

A modification of the Bramante technique (Bramante *et al.* 1987, Hülsmann *et al.* 1999) was used to evaluate simultaneously the cleaning ability as well as preparation form (longitudinal and cross-sectional), safety issues and working time on extracted teeth under conditions comparable with the clinical situation. A muffle-block was constructed, consisting of a U-formed middle section and two lateral walls that are fixed together with three screws. A modification of a radiographic platform, as described by Southard *et al.* (1987) and Sydney *et al.* (1991), could be adjusted to the outsides of the middle part of the muffle. This allowed the exposure of radiographs under standardized conditions to allow the superimposition of views taken before and after root canal preparation. Two metallic reference objects in the film holder facilitated exact superimposition of the radiographs. The system and the evaluation technique have been previously described in detail (Hülsmann *et al.* 1999).

Fifty extracted mandibular molars with two curved mesial root canals were used. After gaining access, the two mesial root canals were checked for apical patency by inserting a size 10 reamer until its tip was just visible beyond the apical foramen. All teeth were shortened to a length of 19 mm, consequently working length for the mesial root canals was 18 mm. The teeth were mounted into the mould with acrylic resin and isolated with rubber dam and a clamp, simulating the clinical situation and ensuring that the operator could only gain access to the root canal from the mesial direction. Root canal curvatures were measured as described by Schneider (1971) from preoperative radiographs after inserting a size 15 reamer. The teeth were randomly divided into two groups, a similar mean degree of root canal curvature was achieved for both groups by exchanging a small number of teeth (ProFile .04: 26.9°, GT: 27.0°). Twenty-five teeth with 50 curved mesial root canals were prepared with the ProFile .04 NiTi system, and 25 teeth with 50 curved root canals were prepared with GT Rotary NiTi rotary instruments.

Instruments and preparation techniques

ProFile .04

The sequence of ProFile .04 instruments used in the present study was the one suggested by the manufacturer. The sequence of instruments and the respective working length are presented in Table 1.

The total number of instruments used was 10.

GT Rotary

The sequence of GT Rotary instruments used in the present study was the one suggested by the manufacturer for severely curved root canals. The sequence of instruments is shown in Table 2.

The total number of instruments used was 10.

All instruments were used in a high torque motor with torque control and constant speed of 250 r.p.m. (Nouvag TCM 3000, Nouvag AG, Goldbach, Switzerland).

In both groups, irrigation was performed with 2-mL NaOCl (3%) after each instrument size. RC-Prep (Premier, Norristown, PA, USA) was used as a chelating

Table 1 Sequence of ProFile .04 instruments

Tip size	Working length
25	14
30	14
20	16
15	18
20	18
25	18
30	18
35	18
40	18
45	18

Table 2 Sequence of GT Rotary instruments

Tip size	Taper	Working length
20	12	12
20	10	14
20	8	14
20	6	16
20	4	18
25	4	18
30	4	18
35	4	18
40	4	18
45	4	18

agent with each instrument. Instruments were discarded after preparation of five root canals.

Assessment of preparation

First, the mesio-buccal root canal was instrumented in the unsectioned teeth. Maintenance of root canal curvature, safety issues (loss of working length, apical blockage, instrument fracture and lateral perforation) and working time were evaluated. Before preparation, a radiograph with a size 15 stainless steel reamer was taken and the initial root canal curvature according to the technique described by Schneider (1971) was determined. Following preparation to size 45, radiographs were taken with a size 40 stainless steel reamer. With the aid of metallic reference objects and traced root contours exact superimposition of the pre- and postoperative radiographs under an X-ray viewer with 10× magnification allowed evaluation of the degree of straightening by measuring the angle between the two instrument tips.

The teeth were sectioned horizontally at 3, 6 and 9 mm from the apex, and the preoperative root canal cross-sections of the mesio-lingual canals were photographed under standardized conditions. The segments were remounted into the mould and the mesio-lingual root canals were prepared to size 45 as described above. Again procedural accidents were recorded and straightening of the root canal curvature was measured by using the superimposed radiographs. At the end of preparation, the cross-sections of the disto-lingual root canal were photographed again. According to Loushine *et al.* (1989), the postoperative cross-sections were classified as round, oval or irregular using reference photographs. Irregular cross-sections were estimated as unacceptable preparation results, because oval cross-sections may be a result of the cutting angle during the sectioning procedure. The divergence of pre- and postoperative root canal cross-section was assessed by superimposing pre- and postoperative canal outlines.

Subsequently, the segments were removed from the mould and the three root segments were split vertically. For the SEM investigation, the mesio-buccal root canals, prepared before sectioning the teeth, were selected because irregular hydrodynamics in the sectioned roots could have influenced the degree of cleanliness. The buccal half of the split root canal segments was prepared for SEM investigation. The roots were coded and mixed so that the type of instrument used for preparation could not be identified during the SEM investigation.

Several evaluations were undertaken for debris and smear layer with a five score system for each using the same set of reference photographs as in previous investigations (Hülsmann *et al.* 1997, 1999, 2001, 2003a,b, Versümer *et al.* 2002). The scores for debris and smear layer are presented in Tables 3 and 4.

Debris was defined as dentine chips, pulp remnants and particles loosely attached to the root canal wall.

Scoring of debris was performed at 200× magnification.

Smear layer was defined as proposed by the American Association of Endodontists' (2003) glossary *Contemporary Terminology for Endodontics* as a surface film of debris retained on dentine or other surfaces after instrumentation with either rotary instruments or

Table 3 Score system for debris

Score	Description
1	Clean root canal wall, only few small debris particles
2	Few small agglomerations of debris
3	Many agglomerations of debris covering <50% of the root canal wall
4	More than 50% of the root canal wall covered by debris
5	Complete or nearly complete root canal wall covered by debris

Table 4 Score system for smear layer

Score	Description
1	No smear layer, dentinal tubules open
2	Small amount of smear layer, some dentinal tubules open
3	Homogeneous smear layer covering the root canal wall, only few dentinal tubules open
4	Complete root canal wall covered by a homogeneous smear layer, no open dentinal tubules
5	Heavy, inhomogeneous smear layer covering the complete root canal wall

endodontic files; consisting of dentine particles, remnants of vital or necrotic pulp tissue, bacterial components and retained irrigant.

Smear layer was scored under 1000× magnification.

After the central beam of the SEM had been directed to the centre of the object by the SEM operator under 10× magnification, the magnification was increased to 200× and 1000×, respectively, and the canal wall region appearing on the screen was scored. The scoring procedure was performed by a second operator who had not prepared the root canals and could not identify the coded specimens and the device used for root canal preparation. This operator had been trained in the scoring procedure intensively, resulting in a sufficient intra-observer reproducibility (Hülsmann *et al.* 1997).

The incidence of procedural accidents (instrument fracture, loss of working length, apical blockage and perforation) was protocolled during the preparation of both unsectioned and sectioned root canals. Apical patency was verified after each step of instrumentation using an ISO 10 reamer extending 1 mm beyond working length.

Statistical analysis

Statistical analysis was performed by using the following tests: for straightening and working time Wilcoxon's test was used ($P < 0.05$); comparison of the cross-sections and root canal cleanliness was performed by using Fisher's exact-test ($P < 0.05$).

Results

Distribution of preoperative root canal curvatures

The mean preoperative root canal curvature was 26.8° in the ProFile .04 and 27.0° in the GT Rotary group. In the ProFile .04, group 2 specimens could not be evaluated because of two instrument fractures.

Straightening

The mean straightening after preparation to size 45 was 0.7° in the ProFile .04 group and 0.3° in the GT Rotary group. The difference was not statistically significant (Wilcoxon's test: unsectioned canals, $P = 0.711$; sectioned canals, $P = 0.113$) (Table 5).

Cross-sections

The results concerning postoperative cross-sections of the root canals are summarized in Table 6. ProFile .04 and GT Rotary prepared nearly similar numbers of round or oval cross-sections (ProFile .04: 80.8%, GT Rotary: 84.0%). The differences were not statistically significant for all three levels of evaluation (Fisher's

Table 6 Evaluation of postoperative cross-section

Section	ProFile .04	Acceptable	GT Rotary	Acceptable
Coronal				
Round	13	22	17	23
Oval	9		6	
Irregular	3		2	
Middle				
Round	9	18	15	21
Oval	9		6	
Irregular	6		4	
Apical				
Round	9	19	4	19
Oval	10		15	
Irregular	5		6	
	$n = 73$[a]		$n = 75$	

[a]Because of two instrument fractures in this group, only 73 specimens could be evaluated.

Table 5 Evaluation of root canal straightening (in degree)

	ProFile .04		GT Rotary	
	Unsectioned roots	Sectioned roots	Unsectioned roots	Sectioned roots
n	24[a]	24[a]	25	25
Mean preoperative curvature	26.8	26.8	27.0	26.9
Min	0	0	0	0
Max	9	3	4	1.5
Mean	0.9	0.5	0.5	0.1

[a]Because of one instrument fracture in each group, the number of root canals evaluated is only 24.

exact-test: coronal, $P = 1$; middle, $P = 0.49$; apical, $P = 1$, respectively).

Superimposition of photographs of the cross-sections of the pre- and postinstrumentation cross-sectional form of the root canals showed that both systems left uninstrumented canal walls. Following preparation with ProFile .04 and GT Rotary instruments, 84.9% and 78.7%, respectively, of all specimens showed <25% contact between the pre- and postoperative canal outlines. Two of 73 specimens in the ProFile .04 group and five of 75 specimens in the GT Rotary group showed more than 50% contact between the pre- and postoperative canal outlines (Table 7).

The difference was statistically significant for the apical third of the root canals (Fisher's exact-test: $P < 0.0255$) with the ProFile .04 system showing a slightly superior performance. For the coronal and the middle third, no significant differences occurred (Fisher's exact-test: coronal, $P = 0.6092$ and middle, $P = 0.7252$, respectively).

Root canal cleanliness

The results of the SEM analysis of the root canal walls concerning residual debris and smear layer are summarized in Table 8. Generally, the root canals showed no homogeneous appearance with only few specimens (ProFile .04: 24.7%, GT Rotary: 28.4%) with completely clean walls without any remaining debris (score 1) and a high number of scores 2 and 3 for both systems (ProFile .04: 63.0%, GT Rotary: 58.1%). Differences between the systems were not significant except for the coronal part of the root canals with superior results for GT Rotary (Fisher's exact-test: coronal, $P = 0.0040$; middle, $P = 1$; apical, $P = 0.3852$, respectively).

In terms of smear layer, only few specimens (ProFile .04: 2.7%, GT Rotary: 4%) presented with completely clean walls without any remaining smear layer (score 1) and a high number of scores 2, 3 and 4 for both systems (ProFile .04: 89.0%, GT Rotary: 80.0%). Differences between the systems were not significant

Table 7 Contact between pre- and postoperative cross-section (in %)

Contact between pre- and postoperative cross-section	ProFile .04				GT Rotary			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
0	11	12	10	33	17	14	10	41
0–25	11	7	11	29	7	7	4	18
>25	2	5	2	9	1	3	7	11
>50	1	0	1	2	0	1	4	5
>75	0	0	0	0	0	0	0	0
n				73[a]				75

[a]Because of two instrument fractures in this group, only 73 specimens could be evaluated.

Table 8 Assessment of root canal cleanliness

Score	ProFile .04				GT Rotary			
	Coronal	Middle	apical	Total	Coronal	Middle	Apical	Total
Debris								
1	6	9	3	18	9	10	2	21
2	11	10	10	31	16	9	7	32
3	7	2	6	15	0	6	5	11
4	0	3	4	7	0	0	5	5
5	1	0	1	2	0	0	5	5
n				73[a]				75
Smear layer								
1	1	1	0	2	1	2	0	3
2	4	6	5	15	8	6	2	16
3	12	9	12	33	11	7	4	22
4	6	6	5	17	4	9	9	22
5	2	2	2	6	2	0	10	12
n				73[a]				75

[a]Because of two instrument fractures, the number of specimens evaluated is only 73.

(Fisher's exact-test: coronal, $P = 0.3487$; middle, $P = 1$; apical, $P = 0.2467$, respectively).

Procedural errors

Two ProFile .04 instruments fractured, one size 35 and one size 45. Furthermore, the ProFile .04 system produced four specimens with loss of working length, additionally four apical blockages occurred. With the GT Rotary system, two specimens with loss of working length and three apical blockages were noted. Loss of working length during preparation with ProFile .04 and GT Rotary in all cases ranged between 0.5 and 1 mm. The total number of complications was five for the GT Rotary system and 10 for the ProFile .04 instruments.

Working time

Mean working time, not including time for instrument changes and irrigation, measured during preparation of the unsectioned roots, was 131.8 s for the ProFile .04 system (10 instruments) and 143.7 s for GT Rotary instrumentation (10 instruments). The difference was not significant (Wilcoxon's test, $P = 0.43$).

Discussion

The present study was one of a series of investigations (Hülsmann *et al.* 2001, Versümer *et al.* 2002, 2003a,b, Paqué *et al.* 2005, Jodway & Hülsmann 2006) on different rotary systems for root canal preparation with identical experimental set-ups, using extracted mandibular first molars.

This study presented data on most aspects important for a definite conclusion on the clinical usefulness of a rotary device, root canal cleanliness, straightening, working safety and working time using a modification of the Bramante muffle model (Bramante *et al.* 1987, Hülsmann *et al.* 1999). Except for the morphology of the natural teeth used for preparation, this model allows good standardization. Simulated root canals allow standardization of root canal cross-section, root canal length and length and radius of canal curvature. On the other hand, the hardness and abrasion behaviour of acrylic resin and root dentine may not be identical (Hülsmann *et al.* 2003a,b) and the heat generated by using rotary instruments in resin blocks may soften the resin material (Kum *et al.* 2000) and lead to binding of cutting blades and separation of the instruments (Baumann & Roth 1999). The present study used natural teeth as this seems to be the only way to evaluate the cleaning ability of a preparation technique.

Straightening of curved canals

In the majority of investigations on NiTi preparation, a superior ability to maintain curvature even in severely curved root canals has been described (Bergmans *et al.* 2001). In the present study, both systems maintained root canal curvature well which is in accordance with other studies (Zmener & Banegas 1996, Short *et al.* 1997, Thompson & Dummer 1997, Schäfer & Zapke 2000, Yared & Kulkarni 2002, Yun & Kim 2003). Peters *et al.* (2001) reported more coronal transportation following the preparation with GT Rotary compared with ProFile .04. In comparison with earlier investigations of other NiTi rotary systems with identical experimental set-ups, preparation with GT Rotary and ProFile .04 resulted in similar degrees of straightening as preparation with HERO 642, LightSpeed, RaCe, ProTaper, FlexMaster, NiTi-TEE and K3 (Versümer *et al.* 2002, Hülsmann *et al.* 2003a,b, Paqué *et al.* 2005, Jodway & Hülsmann 2006). The mean degree of straightening was 0.5° for HERO, 0.4° for LightSpeed, 0.1° for RaCe, 0.1° for ProTaper, 0.6° for FlexMaster, 0.2° for NiTi-TEE and 0.4° for K3, and, respectively, compared with 0.7° for ProFile .04 and 0.3° for GT Rotary in the present study. The study by Versümer *et al.* (2002) resulted in similar results for ProFile .04 (0.2°). As evaluation of straightening was performed by superimposition of radiographs under 10× magnification, it seems questionable whether these differences are of any clinical significance. Calberson *et al.* (2002) also reported good maintenance of root canal curvature for GT Rotary with only slight apical straightening but a high incidence of apical zipping which may be due to the use of plastic canals in that study. They stated that the length of the straight section of the canal determines the direction of transportation more than the angle of the curve. In the 60° curves, a high incidence of instrument deformation was found when using the 0.04-tapered instruments. Park (2001) prepared simulated root canals with ProFile .06 and GT instruments and obtained excellent tapered canals that maintained the original curvature. The canals prepared with GT files showed a slight enlargement towards the inner side at the beginning of the curvature. Concerning ProFile .04 preparation in simulated root canals, Bryant *et al.* (1998b) noticed that transportation was towards the outer aspect of the curve at the end-point of preparation and along the curved portion of canals but more balanced along the straight coronal section. ProFile .04 instruments produced a larger number of zips than expected (24%), but the degree of zipping was limited and relatively minor.

Cross-sections

The comparison of the pre- and postoperative photographs of root canal cross-sections enables evaluation of one of the most important aspects of canal preparation, ie: if the prepared canal completely includes the original canal and no unprepared areas remain. The pre- and postoperative photographs of the root canal cross-sections were superimposed and deviations between the two root canal contours could be measured according to a modification of the Bramante technique (Bramante *et al.* 1987). Both systems prepared the majority of the specimens with round or oval cross-sections, but there were only few specimens with the complete circumference being prepared. GT produced slightly more acceptable cross-sections in the coronal (GT: 92%, ProFile .04: 88%) and middle part (GT: 84%, ProFile .04: 75%) of the root canal, but the differences were not statistically significant. Concerning the apical region, both systems had a similar number of acceptable cross-sections. In contrast, ProFile .04 performed better in the study by Versümer *et al.* (2002) with 92% acceptable cross-sections in the coronal and 96% in the middle and apical part of the root canal.

GT Rotary removed significantly more dentine in the coronal part of the root canal than ProFile .04. In the GT Rotary group, in 17 out of 25 coronal specimens and 14 out of 25 middle specimens no unprepared areas were found. The high amount of dentine removal in the middle and coronal parts of the root canal prepared with GT Rotary is confirmed by other investigations (Calberson *et al.* 2002, Al-Omari *et al.* 2003, Bergmans *et al.* 2003). This probably is due to the increased taper of the GT Rotary Shaping Files of up to 12%, whereas ProFile .04 instruments are restricted to a 4% taper. With regard to the instruments' tapers and sequences used in this study, differences concerning the root canal cross-sections can be expected only coronally of the 7-mm level. At the 7-mm level, NiTi preparation resulted in a root canal diameter of 0.89 mm in the ProFile .04 group and 0.90 mm in the GT Rotary group. Coronally of this level, a further increase of root canal diametre was produced due to the greater taper of the GT instruments. Nevertheless, the differences were not significant. In contrast, in the apical part of the root canals, ProFile .04 performed significantly better. In a comparative study of four NiTi preparation techniques, Peters *et al.* (2001) detected better-tapered root canals in the GT Rotary group compared with ProFile .04, LightSpeed or K-files.

An evaluation of changes in cross-sections of curved root canals showed that ProFile .04 preparation resulted in a rounded canal morphology, with minor variations, in the middle and apical thirds (Gonzalez-Rodriguez & Ferrer-Luque 2004). Furthermore, the amount of dentine removed and the deformities observed were negligible or nonexistent in the apical third, which is consistent with the observations of Jardine & Gulabivala (2000).

Cleaning ability

With none of the systems in the present study could an acceptable cleanliness of root canal walls be obtained. In terms of smear layer, GT instruments obtained a high number of Score 5 in the apical area of the root canal. The difference with the ProFile .04 group cannot be explained because the final apical preparation was performed with ProFile instruments with a taper of 4% and sizes 20–45. There is a possibility that an unusual accumulation of teeth with anatomical variations occurred in the GT group.

Both NiTi systems were unable to remove completely the debris from the apical part of the root canal. Similar results were noted regarding smear layer although a paste-type chelating agent was used during preparation. The results concerning the cleaning ability of ProFile .04 are comparable with those of Versümer *et al.* (2002) who also demonstrated a better performance of ProFile .04 in the coronal and middle third of the root canal.

A study by Suffridge *et al.* (2003) demonstrated that the cleaning efficiency concerning debris removal was similar after using GT and ProFile .04 instruments when used in torque-controlled handpiece compared with a no-torque control setting. Thus, the automatic reversal of the torque-controlled handpiece (Nouvag TCM, Nouvag AG) did not have an impact on the cleaning ability of GT and ProFile .04 instruments.

The superior cleanliness in the coronal parts of the root canal after preparation with rotary NiTi instruments is confirmed by several studies. Prati *et al.* (2004) found increasing amounts of debris and smear layer towards the apical region after preparation with ProFile .04, however they used straight or only slightly curved maxillary incisors in their study. Gambarini & Laszkiewicz (2002) instrumented single-rooted premolars with GT and demonstrated no significant difference between the coronal, middle and apical region of the root canals for debris. Comparison of the amount of the smear layer between the three areas showed that there was a statistically significant difference between all regions, especially between the coronal and apical thirds. This is in agreement with the results of earlier studies on postoperative cleanliness with other rotary systems using identical experimental set-ups (Hülsmann *et al.* 2001, Versümer *et al.* 2002, 2003a,b). The main reason for the inferior cleaning ability of ProFile .04 and GT may be the radial lands of the instruments which perform a planning action rather than a cutting action on the root canal walls (Thompson & Dummer 1997, Schäfer & Fritzenschaft 1999, Jeon *et al.* 2003).

The results on cleaning ability underline the limited efficiency of endodontic instruments in cleaning the apical part of the root canal and the importance of additional irrigation as crucial for sufficient disinfection of the endodontic system. It should be noted that EDTA was used only as paste during preparation and proved to be not sufficient for smear layer removal. A final irrigation with a liquid EDTA solution probably could increase the degree of cleanliness (Calt & Serper 2000).

Procedural errors

In the present study, only two instrument fractures occurred (ProFiles .04 size 35 and 45), which are comparable with an earlier investigation (Versümer *et al.* 2002). These results are in accordance with other studies where the incidence of fractures was enhanced with increasing size of the files, and with most fractures occurring with size 30 and 35 files (Bryant *et al.* 1998a, Baumann & Roth 1999, Guelzow *et al.* 2005). Yun & Kim (2003) found no instrument deformation after ProFile .04 and GT preparation of simulated curved root canals. Furthermore, a recent study confirmed the good working safety of ProFile .04 and GT instruments with no fractures or deformation after use in a torque-controlled engine (Endo IT professional; Aseptico, Woodinville, WA, USA) (Schirrmeister *et al.* 2006). Additionally, in the present study, some cases of loss of working length (in the range of 0.5–1 mm) and apical blockages in each group were observed. Schirrmeister *et al.* (2006) detected mean losses of working distance of 0.19 mm for ProFile .04/.06 and 0.16 mm for GT using an IMAGE analyzer software and simulated root canals. The number of procedural incidents in the present study was slightly higher when compared with similar studies on NiTi instruments (Hülsmann *et al.* 2001, Versümer *et al.* 2002, 2003a,b). It should be noted that a high-torque motor was used in this study. Nevertheless, it seems questionable whether this may be regarded as one possible reason for the relatively high number of intra-operative problems, as the motor was used in both groups with differing results (GT Rotary: five incidents, ProFile .04: 10 incidents). Yared *et al.* (2001) demonstrated that ProFile .04 instruments were safe to use without any fracture with low-torque as well as with high-torque motors.

Working time

The finding that GT Rotary instruments took the same working time as ProFile .04 can be explained by the fact that both systems consist of 10 instruments. In an earlier study, using an identical experimental design preparation with ProFile .04 was completed in a mean time of 94 s (Versümer *et al.* 2002). Differences in working time reflect to a high degree the operators' experience and effectiveness in root canal preparation as the working time for an instrument is not clearly defined. Schirrmeister *et al.* (2006) measured the time required for canal preparation of simulated root canals that included active instrumentation time, irrigation and the time taken to exchange instruments. Preparation time for ProFile .04/.06 (nine instruments) was 5.1 min and for GT (seven instruments) 4.3 min. Hata *et al.* (2002) prepared simulated root canals with a curvature of 20 and 30° with ProFile .04 and GT instruments to size 35 and recorded the total time of instrumentation (including active instrumentation, irrigation and instrument change). GT rotary files (eight instruments) prepared the 20° curved canal in approximately 4.7 min and the 30° canal in 4.2 min. Instrumentation time for ProFile .04 (eight instruments) was 8.3 min (20° canal) and 4.9 min (30° canal), respectively. In the present study, working time including time for irrigation was 3.6 min for ProFile .04 and 4.2 min for GT. Comparison of the results of the present study to the data of Hata *et al.* (2002) and Schirrmeister *et al.* (2006) is difficult because time for instrument change was not recorded. Additionally, the number of instruments and the morphology of the root canals were different. With regard to other investigations with identical experimental set-up (Hülsmann *et al.* 2001, Versümer *et al.* 2002, 2003a,b, Paqué *et al.* 2005), preparations of root canals with ProTaper, HERO 642 and FlexMaster obviously took less time than preparations with RaCe, Quantec SC, ProFile .04 and LightSpeed. This could be due to the superior cutting ability of the active instruments when compared with passive instruments with radial lands such as ProFile .04 and GT Rotary.

Conclusions

The results of the present study confirmed the results of previous studies on rotary nickel–titanium systems concerning maintenance of root canal curvature and centring ability of such instruments. Neither system was able to remove debris and smear layer sufficiently. In terms of procedural errors and instrument fracture, more problems occurred with ProFile .04 than with GT Rotary.

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