Comparison of root canal preparation using RaCe and ProTaper rotary Ni-Ti instruments

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Abstract

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Aim To compare various parameters of root canal preparation using RaCe (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) and ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) nickel-titanium (Ni-Ti) instruments.

Methodology Fifty extracted mandibular molars with mesial root canal curvatures between 20° and 40° were embedded in a muffle system. All root canals were prepared to size 30 using RaCe or ProTaper rotary instruments in low-torque motors with torque control and constant speed of 300 r.p.m. (ProTaper with ATR Tecnika, Advanced Technology Research, Pistoia, Italy; RaCe with EndoStepper, S.E.T., Olching, Germany). In both groups irrigation was performed with 2 mL NaOCl (3%) after each instrument size. Calcinase-Slide (lege artis, Dettenhausen, Germany) was used as a chelating agent with each instrument. The following parameters were evaluated: straightening of curved root canals, postoperative root canal cross-sections, safety issues and working time. Cleanliness of the root canal walls was investigated under the SEM using 5-score indices for debris and smear layer. Statistical analysis was performed using the following tests: Wilcoxon's test for straightening and working time was used ($P < 0.05$); Fisher's exact test for comparison of cross-sections and root canal cleanliness ($P < 0.05$).

Results Both Ni-Ti systems maintained curvature well; the mean degree of straightening was less than 1° for both systems. Following preparation with RaCe, 49% of the root canals had a round or oval diameter and 50% an irregular diameter, ProTaper preparations resulted in a round or oval diameter in 50% of the cases. For debris, RaCe and ProTaper achieved 47 and 49% scores of 1 and 2, respectively; there was no significant difference. For smear layer, RaCe and ProTaper achieved 51 and 33% scores 1 and 2, respectively; no statistically significant differences were apparent for the coronal and middle sections of the root canals, but RaCe performed significantly better in the apical region (Fisher's exact test, $P = 0.0392$). Two roots lost working length with RaCe instruments, whilst ProTaper preparation resulted in two roots loosing working length and one fractured instrument. Mean working time was shorter for ProTaper (90.9 s) than for RaCe (137.6 s); the difference was significant (Wilcoxon's test, $P = 0.011$).

Conclusions Both systems respected original root canal curvature well and were safe to use. Cleanliness was not satisfactory for both systems.

Keywords: automated root canal preparation, Ni-Ti instruments, ProTaper, RaCe.

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Introduction

During the last decade root canal preparation with rotary nickel-titanium (Ni-Ti) instruments has become popular. More recently advanced instrument designs including noncutting tips, radial lands, different cross-sections and varying tapers have been developed to

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improve working safety, to shorten working time, and to create a greater flare of preparations (Bergmans *et al.* 2001).

Numerous studies have shown the ability of rotary Ni-Ti systems to maintain original root canal curvature, to produce a well-tapered root canal form sufficient for obturation, and to complete preparation in an acceptable time (Bergmans *et al.* 2001). Only a few studies have been published investigating the cleaning ability of rotary Ni-Ti files (Hülsmann *et al.* 2001, 2003a,b, Schäfer & Lohmann 2002b, Versümer *et al.* 2002, Schäfer & Schlingemann 2003, Prati *et al.* 2004). Most of these studies have concluded that none of the automated instrumentation devices completely clean the root canal, in particular the apical region of curved canals. Additional concern has been expressed about the comparatively high incidence of fractures of rotary Ni-Ti instruments (Kavanagh & Lumley 1998).

ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) show a convex triangular cross-sectional design with an advanced flute design that combines multiple tapers within the shaft. The system includes seven instruments:

- one SX shaper,
- an orifice opener with tip size 19 and a conicity of 3–19%,
- two Shaping Files with tip sizes 17 and 20 and tapers increasing from 2 to 11%, and 4 to 11.5%, respectively, for crown-down preparation,
- three Finishing Files with tip sizes 20–30 and decreasing conicity (F1: 7–5.5%, F2: 8–5.5%, F3: 9–5%) for apical preparation.

RaCe instruments (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) have a triangular cross-sectional design with alternating cutting edges (straight sector varies with twisted sector) and are claimed to prevent the instrument from screwing into the root canal thus reducing intraoperative torque values. Additionally, the surfaces of RaCe instruments are electrochemically treated for improvement of cutting efficacy. Some of the RaCe instruments for the initial steps of crown-down preparation are manufactured from stainless steel as well as from Ni-Ti alloy. Tapers range from 2 to 10%, sizes from 15 to 60. Different instrument sets for different types of curvature are available.

The aim of the present study was to evaluate several parameters of automated root canal preparation using RaCe and ProTaper Ni-Ti instruments. The parameters evaluated were: straightening of curved root canals, postoperative root canal diameter, root canal cleanliness, incidence of procedural errors such as file fractures, perforations, loss of working length and working time. The same methodology was used as in previous studies (Versümer *et al.* 2002, Hülsmann *et al.* 1999, 2001, 2003a,b) to allow comparisons amongst different Ni-Ti systems.

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 which were fixed together with three screws. Grooves in the walls of the muffle-block allowed removal and exact repositioning of the complete tooth-block or sectioned parts of the tooth. 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 and geometric relationship in order to allow the superimposition of views taken before, during and after root canal preparation. Two metallic reference objects inserted into 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 in this study. After gaining access the two mesial root canals were controlled 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 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 or root canal curvature was achieved for both groups by exchanging a small number of teeth. Twenty-five teeth with 50 curved mesial root canals were prepared with the ProTaper Ni-Ti system, and 25 teeth were prepared with RaCe Ni-Ti rotary instruments.

Instruments and preparation techniques

ProTaper

The sequence of ProTaper instruments used in the present study was the one suggested by the manufacturer for medium length and long root canals. The sequence of instruments was as summarized in Table 1.

The total number of instruments used was 7. All instruments were used in a low-torque motor with torque control and constant speed of 300 r.p.m. (ATR Tecnika; Advanced Technology Research, Pistoia, Italy). No data on the maximum torque were available from the manufacturer, the motor display only presents the 'relative torque' which in this study was 40–100.

RaCe

The sequence of RaCe instruments used in the present study was the one suggested by the manufacturer for severely curved root canals (Table 1).

The total number of instruments used was 9. All instruments were used in a low-torque motor with a constant speed of 300 r.p.m. and a maximum torque of 3.5 N cm (S.E.T., Olching, Germany).

In both groups irrigation was performed with 2 mL NaOCl (3%) after each instrument size. Calcinase-Slide (lege artis, Dettenhausen, Germany) was used as a chelating agent with each instrument. Instruments were discarded after preparation of five root canals.

Table 1 Sequences of instruments as used in this study

Instruments	WL (mm)
ProTaper	
Shaping File No. 1 (tip size: 17; tapers: 2–11%)	14
SX File (tip size: 19; tapers: 3.5–19%)	12
Shaping File No. 1 (tip size: 17; tapers: 2–11%)	18
Shaping File No. 2 (tip size: 20; tapers: 4–11.5%)	18
Finishing File No. 1 (tip size: 20; tapers: 5.5–7%)	18
Finishing File No. 2 (tip size: 25; tapers: 5.5–8%)	18
Finishing File No. 3 (tip size: 30; tapers: 9.5%)	18
RaCe	
PreRaCe File (steel)	
.10/40	9
.06/35	9
.06/30	10
RaCe File (Ni-Ti)	
.02/15	18
.02/20	18
.02/25	18
.02/30	18
.04/25	18
.04/30	18

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, lateral perforation) and working time were evaluated at this stage. Before preparation, a radiograph with a size 15 instrument was taken and the initial root canal curvature was determined using the technique proposed by Schneider (1971). Following preparation to size 25 and 30, respectively, radiographs were again taken with a size 20 or 25 instrument. The radiographs were scanned and saved as a jpg-file. With the software program Adobe Photoshop 6.0 the scanned radiographs were inverted and printed with a 8× magnification on transparent foil. The reference object allowed control of exact superimposition of the pre- and postoperative images. The degree of straightening was evaluated by measuring the angle between the instrument tips.

The teeth were sectioned horizontally at 3, 6 and 9 mm from the apex, and the preoperative root canal diameters of the mesio-lingual canals were photographed under standardized conditions with a 5× magnification. The horizontal segments were remounted into the mould which was facilitated by horizontal grooves, and the mesio-lingual root canals were prepared to size 30 as described above. Again procedural accidents were recorded and straightening of the root canal curvature was measured using the superimposed foils. 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. Only irregular cross-sections were regarded as unacceptable preparation results because an oval cross-section may be as a result of the cutting angle during the sectioning procedure. The divergence of pre- and postoperative root canal diameter was evaluated by superimposing pre- and postoperative canal outlines.

Following this, the segments were removed from the mould and the three root segments were freed from the resin and split vertically with a chisel after preparation of two longitudinal grooves. For the SEM investigation, the mesio-buccal root canals, prepared before sectioning the teeth, were selected as 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.

Separate 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).

Debris was defined as dentine chips, pulp remnants and particles loosely attached to the root canal wall. Smear layer was defined as proposed by the American Association of Endodontists (1994) glossary 'Contemporary Terminology for Endodontics' as a surface film of debris retained on dentine or other surfaces after instrumentation with either rotary instruments or endodontic files; consisting of dentine particles, remnants of vital or necrotic pulp tissue, bacterial components and retained irrigant. The scores for debris and smear layer are presented in Table 2.

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, resulting in sufficient intraobserver reproducibility (Hülsmann *et al.* 1997).

The incidence of procedural accidents was recorded during preparation of both the unsectioned and sectioned root canals. Apical patency was controlled after each step of instrumentation using a size 10 reamer extending 1 mm beyond working length.

Table 2 Scores for debris and smear layer

Debris
Score 1: Clean root canal wall, only few small debris particles
Score 2: Few small agglomerations of debris
Score 3: Many agglomerations of debris covering less than 50% of the root canal wall
Score 4: More than 50% of the root canal wall covered by debris
Score 5: Complete or nearly complete root canal wall covered by debris
Scoring of debris was performed using 200× magnification
Smear layer
Score 1: No smear layer, dentinal tubules open
Score 2: Small amount of smear layer, some dentinal tubules open
Score 3: Homogeneous smear layer covering the root canal wall, only few dentinal tubules open
Score 4: Complete root canal wall covered by a homogeneous smear layer, no open dentinal tubules
Score 5: Heavy, inhomogeneous smear layer covering the complete root canal wall
Smear layer was scored under 1000× magnification

Statistical analysis

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

Results

Distribution of preoperative root canal curvatures

The mean preoperative root canal curvature in the teeth of the ProTaper group ($n = 25$ teeth) was 28.5° and in the RaCe group ($n = 25$ teeth) 28.0°.

In the ProTaper group three root canals from 50 could not be evaluated due to apical blockages and one instrument fracture, in the RaCe group two root canals from 50 were lost due to blockages.

Straightening

The mean straightening after preparation to size 30 in the ProTaper group ($n = 47$ root canals) was 0.8° (SD 0–15°) and in the RaCe group ($n = 48$ root canals) was 0.9° (SD 0–12°). The difference was not statistically significant (Wilcoxon's test: unsectioned canals, $P = 1$; sectioned canals, $P = 0.787$) (Table 3).

Table 3 Evaluation of root canal straightening (in °)

	RaCe		ProTaper	
	Unsectioned roots	Sectioned roots	Unsectioned roots	Sectioned roots
n	25	23[a]	24[b]	23[a]
Mean preoperative curvature	27.8	28.2	28.6	28.4
Min	0	0	0	0
Max	0	12	0	15
Mean	0	1.8	0	1.6

[a]Due to loss of working length in this group the number of root canals evaluated is only 23.
[b]Due to one instrument fracture in this group the number of root canals evaluated is only 24.

Cross-sections

The results concerning postoperative cross-sections of the root canals are summarized in Table 4. ProTaper and RaCe instruments prepared nearly similar round or oval diameters (ProTaper: 50%; RaCe 49%). In the middle region of the root canal ProTaper produced more round and oval cross-sections, in the apical part RaCe produced more regular cross-sections. However, the differences were not statistically significant for all three levels of evaluation (Fisher's exact test: coronal, $P = 1$; middle, $P = 0.1482$; apical, $P = 0.1482$).

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 ProTaper and RaCe instruments, 80 and 53%, respectively, of all specimens showed less than 25% contact between the pre- and postoperative canal outlines. Eight of 74 specimens in the ProTaper group and 19 of 75 specimens in the RaCe group showed more than 50% and more contact between the pre- and postoperative canal outlines (Table 5).

Table 4 Evaluation of root canal diameter

Section	RaCe	Acceptable	ProTaper	Acceptable
Coronal				
Round	1	12	10	12
Oval	11		2	
Irregular	13		13	
Medial				
Round	8	12	16	18
Oval	4		2	
Irregular	13		7	
Apical				
Round	6	13	6	7
Oval	7		1	
Irregular	12		17	
n	75		74[a]	

[a]Due to one instrument fracture (in the apical third of the root canal) in this group, only 74 specimens could be evaluated.

The difference was statistically significant for the coronal third of the root canals (Fisher's exact test: $P < 0.0001$) with the ProTaper system showing a superior performance. For the apical and the middle third no significant differences occurred (Fisher's exact test: middle, $P = 0.1137$ and apical, $P = 0.7624$).

Root canal cleanliness

The results of the SEM analysis of the root canal walls concerning residual debris and smear layer are summarized in Table 6. Generally, the root canals showed no homogeneous appearance with only few specimens (ProTaper: 11%, RaCe: 11%) with completely clean walls without any remaining debris (score 1) and a high number of scores 2 and 3 for both systems (ProTaper: 72%, RaCe: 61%). Differences between the systems were not significant (Fisher's exact test: coronal, $P = 1$; middle, $P = 0.7761$; apical, $P = 1$).

In terms of smear layer, the ProTaper and RaCe preparations resulted in 33 and 51% of specimens having scores 1 and 2, respectively. No statistically significant differences were apparent for the coronal ($P = 0.2443$) and middle parts ($P = 1$) of the root canals, but RaCe performed slightly significantly better in the apical region ($P = 0.0392$).

Procedural errors

Only one file (Finishing File No. 3) fractured with the ProTaper instruments. Furthermore, the ProTaper system produced two specimens with loss of working length, but no perforations and no apical blockages occurred. The RaCe system produced two specimens with loss of working length, no instrument fractures, perforations or apical blockages were noted. Loss of working length during preparation with ProTaper and RaCe in all cases ranged between 1 and 2 mm.

Table 5 Percentage contact between superimposed pre- and postoperative root canal walls when viewed in cross-section

Contact between pre- and postoperative cross-section (%)	RaCe				ProTaper			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
>75	4	2	1	7	0	0	2	2
>50	6	2	4	12	1	1	4	6
>25	9	6	2	17	2	3	2	7
0–25	5	9	10	24	3	1	3	7
0	1	6	8	15	19	20	13	52
n				75				74[a]

[a]Due to instrument fracture the number of specimens evaluated is less than 75.

Table 6 Assessment of root canal cleanliness

	RaCe				ProTaper			
Score	Coronal	Medial	Apical	Total	Coronal	Medial	Apical	Total
Debris								
1	4	4	0	8	5	3	0	8
2	9	9	8	26	7	12	8	27
3	8	6	5	19	9	8	8	25
4	2	5	6	13	1	2	6	9
5	1	1	5	7	2	0	1	3
n				73[a]				72[b]
Smear layer								
1	4	4	1	9	4	2	0	6
2	9	6	13	28	4	8	6	18
3	4	7	3	14	8	8	7	23
4	7	6	5	18	7	5	3	15
5	0	2	2	4	1	2	7	10
n				73[a]				72[b]

[a]Due to loss of two specimens the number of specimens evaluated is 73.
[b]Due to one instrument fracture the number of specimens evaluated is only 72.

Working time

Mean working time, not including time for instrument changes and irrigation, measured during preparation of the unsectioned roots, resulted in a median of 90.9 s for ProTaper instrumentation (seven instruments), and 137.6 s for the RaCe system (nine instruments). The difference was statistically significant (Wilcoxon's test, $P = 0.011$).

Discussion

For evaluation of root canal preparation two methods have been used constantly; either extracted human teeth or simulated root canals with strictly defined root canal curvatures in terms of angle and radius. Simulated root canals allow standardization of root canal diameter, root canal length, and length and radius of canal curvature. On the contrary, the hardness and abrasion behaviour of acrylic resin and root dentine may not be identical. The present study used natural teeth although these show large variations in dentine hardness and root canal morphology, but their use seems to be the only way to evaluate the cleaning ability of a preparation technique. Nevertheless, great care was taken to standardize the preparation and evaluation procedures.

The present study is one of a series of investigations (Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b) on different rotary systems for root canal preparation with identical experimental set-ups, using extracted mandibular first molars. This should allow comparisons amongst the different systems.

Straightening of curved canals

In the majority of investigations on Ni-Ti systems a superior ability to maintain curvature even in severely curved root canals has been described (Thompson & Dummer 1997a,b,c,d, 1998a,b, Schäfer & Lohmann 2002a, Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b, Schäfer & Florek 2003). ProTaper and RaCe Ni-Ti systems both have been introduced only recently and little information on their shaping ability is available. In the present study, both systems maintained root canal curvature well. The different instrument designs (i.e. progressive versus constant taper) seem to have no influence on the ability to respect root canal curvature. Peters *et al.* (2003) reported apical canal transportation after preparation of curved root canals in extracted human maxillary molars with ProTaper. Yun & Kim (2003) prepared simulated root canals with curvatures between 34° and 35° using ProTaper. They found only a small amount of change in terms of root canal curvature. In comparison with earlier investigations of other Ni-Ti rotary systems with identical experimental set-ups, preparation with ProTaper and RaCe resulted in slightly more straightening than preparation with HERO 642, Lightspeed and FlexMaster (Versümer *et al.* 2002, Hülsmann *et al.* 2003a). The mean degree of straightening was 0.4° for Lightspeed, 0.4° for FlexMaster and 0.6° for HERO, compared with 0.9° for RaCe and 0.8° for ProTaper in the present study. As evaluation of straightening was performed by overprojection under 10× magnification it seems questionable whether these differences are of any clinical significance. However, apical preparation with HERO 642, Lightspeed and FlexMaster was performed up to size 45 whilst preparation with RaCe and ProTaper was limited to apical size 30. This limitation was necessary to assure equal conditions for both groups, although the file set of RaCe would have allowed preparation to larger sizes, whereas ProTaper does not allow preparation exceeding size 30. Whether the use of larger RaCe instruments in consequence would have resulted in increased straightening must remain speculative.

The comparison of the pre- and postoperative photographs of root canal diameter enables the evaluation one of the most important requirements of root canal preparation, that is, the prepared canal should completely include the original canal and no unprepared areas should remain. Using a modification of the Bramante technique (Bramante *et al.* 1987), pre- and postinstrumentation photographs of the root canal diameter were superimposed and deviations between the two root canal outlines could be measured. Both systems prepared half of the specimens with round or oval diameters. Whilst RaCe produced a similar number of acceptable cross-sections in all root canal sections (48–52%), ProTaper prepared 48% round or oval diameters in the coronal, 72% in the middle part and only 29% round or oval diameters in the apical part of the root canal.

Additionally, ProTaper showed significantly more dentine removal in the coronal part of the root canal than RaCe. In the ProTaper group, in 19 of 25 coronal specimens and 20 of 25 middle specimens no unprepared areas were found. The greater amount of dentine removal in the middle and coronal parts of the root canal prepared with ProTaper has been confirmed by other investigations (Al-Omari *et al.* 2003, Bergmans *et al.* 2003, Calberson *et al.* 2003). This is due probably to the increased taper of the ProTaper Shaping Files of up to 19%, whereas RaCe instruments are available only with tapers of maximum 10%.

Cleaning ability

With none of the systems in the present study could an acceptable cleanliness of root canal walls be obtained. In terms of debris both systems got predominantly score 2 and 3 in all specimens with worst results for the apical part of the root canal (no score 1 was obtained in this section).

Similar results were recorded regarding smear layer although a paste-type chelating agent was used during preparation. Although more chelator paste and irrigant were used in the RaCe group, due to the larger number of instruments used for preparation no significant differences between the groups were found. It should be noticed that for practical reasons the buccal halves of the roots were investigated for cleanliness. On the lingual halves probably another degree of cleanliness as well as uninstrumented and uncleaned isthmi might have been detected.

The superior cleanliness in the coronal parts of the root canal after preparation with rotary Ni-Ti instruments is confirmed by several studies. Schäfer & Vlassis (2004b) found significantly less debris but more smear layer after preparation with RaCe when compared with ProTaper. For smear layer they found 27.3% (ProTaper) and 23.8% (RaCe) scores 1 and 2, the results from the present study were 33% scores 1 and 2 for ProTaper and 51 % for RaCe. Prati *et al.* (2004) found increasing amounts of debris and smear layer towards the apical region after preparation with RaCe, however they used straight or slightly curved maxillary incisors in their study. This is in agreement with the results of earlier studies on postpreparation cleanliness after use of other rotary Ni-Ti systems and identical experimental set-ups (Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b). It may be surmised that different instrument designs influence the formation and removal of debris and smear layer. In the present study, sharp-bladed active instruments with a triangular cross-section have been used for root canal preparation. When compared with passive instruments with U-shaped cross-sections and radial lands no differences between the two design features in terms of removal of debris and smear layer are obvious (Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b). 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, a final irrigation with a liquid EDTA solution probably could increase the degree of cleanliness.

Working safety

High numbers of instrument fractures (up to 10%) have been reported for Ni-Ti files in several earlier studies (Kavanagh & Lumley 1998), indicating that Ni-Ti instruments are more susceptible to failure than conventional stainless steel instruments. In the present study, only one instrument fracture occurred (ProTaper

F3). Additionally, two cases with loss of working length in each group were observed (in the range of 1–2 mm), further procedural incidents were not recorded. Peters *et al.* (2003) reported no obvious procedural errors or instrument fractures preparing human maxillary molars with ProTaper. Yared *et al.* (2003) prepared mandibular and maxillary molars with ProTaper and investigated the influence of different torque control motors and the operator's experience. Using a motor with low-torque and torque control and an experienced operator no instrument was separated or deformed. Investigations in simulated root canals with ProTaper resulted in no more than two instrument fractures (Al-Omari *et al.* 2003, Calberson *et al.* 2003, Yun & Kim 2003), however up to 10 instruments deformed whilst preparing 40 simulated root canals. Schäfer & Vlassis (2004a,b) in a comparative study of RaCe and ProTaper reported on few instrument fractures but large numbers of deformed instruments and mean losses of working length of 0.16–0.38 mm in both groups. Additionally, they reported some ledges and zips/elbows for each system. The number of procedural incidents in the present study was lower when compared with similar studies on Ni-Ti instruments (Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b). Whereas in the previous investigations a high-torque motor (Nouvag TC 3000; Nouvag, Goldbach, Switzerland) had been used, in the present study low-torque motors with constant speed and torque-control were used.

Summarizing, all of the published studies have reported no differences in safety between ProTaper and RaCe.

Working time

The finding that ProTaper instruments took less working time than RaCe was due largely to the fact that the number of instruments used differed (RaCe: 9; ProTaper: 7). Schäfer & Vlassis (2004a) recorded a shorter working time for Race in plastic canals but no difference in extracted teeth, but they used sequences with seven instruments in both groups. Additionally, performing root canal preparation with RaCe instruments in some cases it proved difficult to reach working length with the last two instruments (04/25 and 04/30, respectively). Probably the RaCe file with its new design (reamer with alternating cutting edges) is not as effective compared with other active Ni-Ti rotary instruments due to the straight sections of the instrument which reduce the contact area between dentine and instrument. Yun & Kim (2003) prepared simulated root canals with an average time of 34 s with ProTaper. Although they used one less instrument, preparation time was much shorter than in the present study. With regard to other investigations with identical experimental set-up (Versümer *et al.* 2002, Hülsmann *et al.* 2001, 2003a,b) preparations of root canals with ProTaper, HERO 642 and FlexMaster obviously took less time than preparations with ProFile, Quantec SC, RaCe and Lightspeed. Except RaCe, this could be due to the superior cutting ability of the active instruments when compared with passive instruments with radial lands.

Conclusions

The results of the present study confirm the results of previous studies on rotary Ni-Ti systems concerning maintenance of root canal curvature and centring ability. Both systems were not able to remove debris and smear layer completely. In terms of procedural errors and instrument fracture both systems were safe.

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