A comparative study of root canal preparation using FlexMaster and HERO 642 rotary Ni–Ti instruments

M. Hülsmann, G. Gressmann & F. Schäfers
Department of Operative Dentistry, Preventive Dentistry and Periodontology, University of Göttingen, Germany

Abstract

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Aim To compare several parameters of root canal preparation using two different rotary nickel–titanium (Ni–Ti) instruments: FlexMaster (VDW, Munich, Germany) and HERO 642 (Micro-Mega, Besançon, France).

Methodology Fifty extracted human mandibular molars with root canal curvatures between 20 and 40° were embedded into a muffle system. All root canals were prepared to size 45 using a high-torque motor with two different Ni–Ti instruments, FlexMaster and HERO 642. In both groups, irrigation was performed with 2 mL NaOCl (3%) after each instrument size. RC-Prep (Premier, Philadelphia, USA) was used as a chelating agent with each instrument. The following parameters were evaluated: straightening of curved root canals, postoperative root canal diameter, working safety (file fractures, perforations, apical blockages, loss of working length), cleaning ability and working time. Statistical analysis was performed using the Wilcoxon's test ($P < 0.05$) for straightening and Fishers's exact test ($P < 0.05$) for comparison of cross-sections, contact between pre- and postoperative diameter, root canal cleanliness and working time.

Results Both Ni–Ti systems maintained the curvature well: the mean degree of straightening was 0.6° for FlexMaster and 0.5° for HERO 642. One file was fractured with the FlexMaster system, but further procedural incidents were not recorded. Following preparation with FlexMaster, 18% of the root canals had a round diameter, 53% an oval diameter and 29% an irregular diameter; HERO 642 preparations resulted in a round diameter in 25%, oval shape in 47% and irregular cross-sections in 28% of the cases. Mean working time was shorter for HERO 642 (66.0 s) than for FlexMaster (71.1 s). Cleanliness of the root canal walls was investigated under the SEM using 5-score indices for debris and smear layer. For debris, HERO 642 and FlexMaster achieved 73 and 70% scores of 1 and 2, respectively. The results for smear layer were similar: HERO 642 and FlexMaster achieved 33 and 26% scores of 1 and 2, respectively. Significant differences between the two systems were not detected for any of the parameters evaluated.

Conclusions Both systems respected original root canal curvature well and were safe. Both systems failed to remove debris and smear layer in the majority of the cases.

Keywords: automated root canal preparation, FlexMaster, HERO 642, Ni–Ti instruments.

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Introduction

Root canal instruments manufactured from nickel–titanium (Ni–Ti) alloy have become an important part of the endodontic armamentarium. The development of new design features such as varying tapers, noncutting safety tips and varying length of cutting blades in combination with the metallurgic properties of Ni–Ti alloy (Thompson 2000) have resulted in a new generation of instruments and concepts. Many of these newly developed Ni–Ti systems have been investigated only with regard to their ability to maintain curvature in severely curved root canals. Additional factors of major importance such as working safety and frequency of pro-

Correspondence: PD Dr M. Hülsmann, Department of Operative Dentistry, Preventive Dentistry and Periodontology, Zentrum ZMK, Robert-Koch-Street 40, 37075 Göttingen, Germany (Tel.: +49 551 392855; fax: +49 551 392037; e-mail: michael.huelsmann@med.uni-goettingen.de).

cedural accidents or cleaning ability of many systems require further investigation.

Few studies have been presented on the rotary Ni–Ti system FlexMaster (VDW, Munich, Germany) (Schäfer & Lohmann 2002a,b, Weiger *et al.* 2002). FlexMaster instruments show a convex cross-section without radial lands and three cutting edges with a negative cutting angle, resembling K-files. The tip of the FlexMaster instruments is noncutting; the sequence of instruments includes tapers .06, .04 and .02 and the sizes range from 20 to 45. The number of instruments available at the time of this investigation was 13. The manufacturer recommends a working speed of 150–300 r.p.m. and the use of a low-torque motor.

HERO 642 (Micro-Mega, Besançon, France) shows similar design features: a noncutting tip, a negative cutting angle, a triangular cross-section with three cutting edges. The instrument set includes tapers .02, .04 and .06; instrument sizes range from 20 to 45. The total number of instruments available is 12. The recommended working speed is 300–600 r.p.m. The main difference between the two systems concerns the proposed sequence of instruments for preparation.

The aim of the present study was to evaluate several parameters of automated root canal preparation using FlexMaster and HERO 642 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.

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 to 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 so that pre- and postoperative views could be superimposed. 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 opened and controlled for apical patency of the mesial root canals; a size 10 reamer was inserted until its tip could be visualized beyond the apical foramen. All teeth were shortened to a length of 19 mm. The teeth were mounted into the mould with acrylic resin and isolated with a 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 insertion of a size 15 reamer. The teeth were randomly divided into two groups. By exchanging a small number of teeth, a similar mean degree of curvature was achieved for both groups. Twenty-five teeth with 50 curved mesial root canals were prepared with the FlexMaster Ni–Ti system (VDW), and 25 teeth were prepared with HERO 642 Ni–Ti rotary instruments (Micro-Mega).

Instruments and preparation techniques

FlexMaster

The sequence of FlexMaster instruments used in the present study was the one suggested by the manufacturer for narrow and severely curved canals. The sequence of instruments was as follows (Fig. 1):

- 6% taper, size 20, WL 12 mm.
- 4% taper, size 30, WL 15 mm.
- 4% taper, size 25, WL 16 mm.
- 4% taper, size 20, WL 17 mm.
- 2% taper, size 20, WL 18 mm.

In addition to the manufacturer's recommendations, the following instrument was used for completion of apical enlargement:

- 2% taper, size 25–45, WL 18 mm.

The total number of instruments used was 10. All instruments were used in a high-torque motor with torque control and constant speed of 350 r.p.m. (Nouvag TC 3000, Nouvag, Konstanz, Germany).

HERO 642

The sequence of HERO 642 instruments used in the present study was the one proposed by the manufacturer for severely curved canals (Fig. 1):

- 6% taper, size 20, WL 12 mm.
- 4% taper, size 20, WL 16 mm.

- 2% taper, size 20, WL 18 mm.
- 4% taper, size 25, WL 16 mm.
- 2% taper, size 25, WL 18 mm.
- 2% taper, size 30, WL 18 mm.

In addition to the manufacturer's recommendations, the following instrument was used for completion of apical enlargement:

- 2% taper, sizes 35–45, WL 18 mm.

The total number of instruments used was 9. All instruments were used with a dental handpiece in a high-torque motor with torque control 100–550 g cm^{-2} and constant speed of 350 r.p.m. (Nouvag TC 3000).

In both groups, irrigation was performed with 2 mL NaOCl (3%) after each instrument size. RC-Prep (Premier, Philadelphia, USA) was used as a chelating agent with each instrument. Instruments were discarded after preparation of 10 root canals.

System	FlexMaster		HERO 642	
		WL		WL
	.06/20	12mm	.06/20	12mm
	.04/30	15mm	.04/20	16mm
	.04/25	16mm	.02/20	18mm
	.04/20	17mm	.04/25	16mm
	.02/20	18mm		
	.02/25	18mm	.02/25	18mm
	.02/30	18mm	.02/30	18mm
	.02/35	18mm	.02/35	18mm
	.02/40	18mm	.02/40	18mm
	.02/45	18mm	.02/45	18mm
No. of instruments	10		9	

Figure 1 Sequence of instrument sizes and respective working lengths used in the study.

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 time. 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 35 and 45, respectively, radiographs were again taken with a size 30 or 40 instrument. The outlines of the inserted instruments, the root outlines and the metallic reference objects in the film holder were superimposed under an X-ray viewer with a 10× magnification, and the degree of straightening was evaluated by measuring the angle between the two instrument tips. The reference objects allowed control of exact superimposition of the radiographs.

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. The horizontal segments were remounted into the mould which was facilitated by the horizontal grooves, 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 using the radiographic platform. At the end of preparation, the cross-section of the disto-lingual root canal was 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. For the SEM investigation, the mesio-buccal root canals, prepared before sectioning the teeth, were selected as irregular hydrodynamics during irrigation 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 SEM investigation.

Separate evaluations were undertaken for debris and smear layer with a 5-score index for each using the same set of reference photographs as in previous investigations (Hülsmann 2000, Hülsmann *et al.* 1997; 1999; 2001, Versümer *et al.* 2002).

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

- 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 a 200× magnification.

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.

- 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 a 1000× magnification. After the central beam of the SEM had been directed to the centre of the object by the SEM operator under a 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 specimen and the device used for root canal preparation. This operator had been trained in the scoring procedure intensively, resulting in a sufficient intraobserver reproducibility (Hülsmann *et al.* 1997).

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

Statistical analysis

Statistical analysis was performed using the Wilcoxon's test ($P < 0.05$) for straightening and Fishers's exact test ($P < 0.05$) for comparison of cross-sections, for comparison of contact between pre- and postoperative diameter, root canal cleanliness and working time.

Results

Distribution of preoperative root canal curvatures

The mean preoperative root canal curvature in the teeth of the HERO 642 and the FlexMaster groups was 26.3° (minimum: 29°, maximum: 35.5°) and 27.1° (minimum: 20°, maximum 38°), respectively.

Straightening

The mean straightening after preparation to size 45 in the FlexMaster group was 0.6° (SD, 0–4.5°) and in the HERO 642 group was 0.5° (SD, 0–5°). The difference was not statistically significant (Wilcoxon's test: unsectioned canals, $P = 0.533$; sectioned canals, $P = 0.083$) (Table 1).

Cross-sections

The results concerning postoperative cross-sections of the root canals are summarized in Table 2. In the majority of the cases, both systems prepared round or oval diameters (FlexMaster: 70.8%; HERO 642: 72.0%). In all parts of the root canals, only minor differences between the two rotary systems were found. The differences were not statistically significant for all three levels of evaluation (coronal, $P = 0.567$; middle, $P = 0.725$ and apical, $P = 0.502$, respectively).

Superimposition of photographs of the pre- and postinstrumentation cross-sectional form of the root canals showed that both systems left uninstrumented canal walls. Following preparation with FlexMaster and HERO 642 instruments, 44 and 55%, respectively, of all canals showed less than 25% contact between the pre- and postoperative canal outlines. Only two specimens in the FlexMaster group and three specimens in the HERO 642

Table 1 Evaluation of root canal straightening (in °)

	FlexMaster		HERO 642	
	Unsectioned roots	Sectioned roots	Unsectioned roots	Sectioned roots
n	25	24*	25	25
Mean preoperative curvature	27.5	26.7	26.8	25.9
Minimum	0	0	0	0
Maximum	3	4.5	5	3
Median	0	0	5	0
Mean	0.3	0.6	0.4	0.8

*As a result of one instrument fracture in this group, the number of root canals evaluated is only 24.

Table 2 Evaluation of postoperative cross-section

Section	FlexMaster	Acceptable	HERO 642	Acceptable
Coronal				
Round	4	13	4	16
Oval	9	13	12	16
Irregular	11	13	9	16
Medial				
Round	6	19	8	21
Oval	13	19	13	21
Irregular	5	19	4	21
Apical				
Round	3	19	7	17
Oval	16	19	10	17
Irregular	5	19	8	17
	$n = 72$*		$n = 75$	

*As a result of one instrument fracture in this group, only 72 specimens could be evaluated.

group showed 50% and more contact between pre- and postoperative canal outlines (Table 3).

The differences were not significant for any of the levels of evaluation (Fishers's exact test: coronal, $P = 0.189$; middle, $P = 0.638$ and apical, $P = 0.310$, 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 4. Generally, the root canals showed only small amounts of remaining debris resulting in a high number of category 1 and 2 scores for both systems (HERO 642: 73%; FlexMaster: 70%). Differences between the systems were not significant (Fisher's exact test: coronal, $P = 0.807$; middle, $P = 0.804$ and apical, $P = 0.919$, respectively).

In terms of smear layer, the FlexMaster and HERO 642 systems resulted in 26 and 33% of specimens having scores 1 and 2, respectively. No statistically significant differences were apparent for the coronal ($P = 0.927$) and the middle parts ($P = 0.689$) of the root canals, but HERO 642 performed slightly significantly better in the apical region ($P = 0.031$).

Table 3 Percentage contact between superimposed pre- and postoperative root canal walls when viewed in cross-section

Contact between pre- and postoperative cross-section (%)	FlexMaster				HERO 642			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
>75%	1	0	0	1	1	0	0	1
>50%	1	0	0	1	0	1	1	2
>25%	7	7	6	20	2	4	2	8
0–25%	9	5	4	18	11	5	7	23
0%	6	12	14	32	11	15	15	41
n				72*				75

*As a result of one instrument fracture in this group, only 72 specimens could be evaluated.

Table 4 Assessment of root canal cleanliness

	FlexMaster				HERO 642			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
Debris score								
1	13	6	3	22	11	8	5	24
2	8	11	8	27	10	11	8	29
3	1	6	9	16	2	4	8	14
4	2	1	2	5	1	2	1	4
5	1	1	1	3	0	0	2	2
n				70*				73*
Smear Layer score								
1	4	1	0	5	5	0	0	5
2	7	7	0	14	8	8	3	19
3	8	12	8	28	8	12	8	28
4	4	4	15	23	2	2	9	13
5	2	1	0	3	1	3	4	8
n				70*				73*

*As a result of loss of specimens, the number of specimens evaluated was less than 75.

Procedural errors

Only one file (.04/20) fractured with the FlexMaster instruments. No cases of apical blockage, loss of working length or perforation occurred with either system.

Working time

Mean working time, not including time for instrument changes and irrigation measured during preparation of the unsectioned roots, was 66.0 s for HERO 642 instrumentation (9 instruments) and 71.1 s for the FlexMaster system (10 instruments). The difference was statistically not significant (Fisher's exact test, $P = 0.137$).

Discussion

For evaluation of root canal preparation, two methods have been described most often: one uses extracted human teeth and the other simulated root canals with strictly defined root canal curvatures in terms of angle and radius. The advantages and shortcomings of both techniques have been discussed previously. Simulated root canals allow standardization of root canal diameter, 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. Natural teeth show large variations in root canal morphology, but their use seems to be the only way to evaluate the cleaning ability of a preparation technique. Thompson & Dummer (1997a,b,c,d; 1998a,b; 2000a,b) and Bryant *et al.* (1998a,b) have presented several reports on the main rotary Ni–Ti systems using artificial root canals. All these studies were undertaken using uniform protocols allowing comparison of different Ni–Ti systems. The present study is one of a series of investigations (Hülsmann 2000, Hülsmann *et al.* 2001, Versümer *et al.* 2002) on different rotary systems for root canal preparation with identical experimental set-ups, but using extracted human teeth. This should allow comparisons amongst the different systems. Because of the limitations of both evaluation techniques, a final comparison of the results of both series of investigations would not provide a conclusion on the clinical suitability of these rotary Ni–Ti systems.

This study presents data on some relevant criteria 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 variations in the morphology of natural teeth, this model allows standardization and reproducibility of the materials and methods. Additionally, it is the only way to evaluate cleaning ability of preparation systems inside the root canal.

Straightening of curved canals

Because Ni–Ti rotary instruments for root canal preparation have been introduced into endodontics, many studies have been published evaluating their suitability for clinical use. In the majority of these investigations, a superior ability to maintain curvature even in severely curved root canals has been described (Short *et al.* 1997, Thompson & Dummer 1997a;b;c;d, 1998a;b, 2000a;b, Bryant *et al.* 1998a;b, Schäfer & Fritzenschaft 1999, Hülsmann *et al.* 2001, Versümer *et al.* 2002). In the present study, both systems maintained root canal curvature well. Good results have been described already for FlexMaster by Schäfer & Lohmann (2002a), who in simulated root canals with curvatures of 28 and 35°, found less straightening and fewer canal aberrations than after preparation with stainless steel K-Flexofiles. In the present study, the results for HERO 642 were not significantly different from those obtained for FlexMaster, probably as a result of the similar design. The differences in the sequence of the instruments seem to have had no measurable influence on the preparation form. It should be kept in mind that preparation protocols using strictly predetermined sequences of instruments and working lengths are contrary to current thinking. Although both should be determined with respect to the individual root canal anatomy in the present study, the instruments were used as proposed by the manufacturers. Interestingly, the results for HERO 642 were comparable to those of a recent study investigating HERO 642 and Quantec SC rotary Ni–Ti instruments under identical experimental conditions but with different operators (Hülsmann *et al.* 2001). The mean values for straightening of HERO 642 instruments in the two studies were 0.4° (present study) and 1.26° (Hülsmann *et al.* 2001). This may confirm the results of previous investigations (Petiette *et al.* 1999, Gluskin *et al.* 2001), demonstrating less influence of the operator's fatigue and experience on preparation result when using Ni–Ti instruments than that for hand instrumentation using stainless steel instruments.

In a comparative study of HERO 642 and ProFile .04/.06, HERO 642 showed the best centring ability with only a few minor deviations from the original curvature (Schäfer & Fritzenschaft 1999). The same result was

obtained in a comparative study of HERO 642 and Quantec SC using extracted teeth (Hülsmann *et al.* 2001). In a study on simulated root canals, HERO 642 created only few aberrations such as zips and elbows and only little transportation toward the outer aspect of the curvature (Thompson & Dummer 2000b). In the present investigation, no significant difference between HERO 642 and FlexMaster was found; both systems maintained curvature well, although apical preparation was performed up to size 45. Limiting apical preparation to size 35, the mean straightening for FlexMaster would have been 0.1° and for HERO 642 0.4°, which demonstrates that the major portion of straightening for HERO 642 appeared during initial preparation to size 35 whilst FlexMaster only showed minimal straightening up to size 35, with the major portion of straightening resulting from the use of instrument sizes 40 and 45. The reason for this difference remains unclear, and repeated investigation should be performed to eventually confirm this finding.

The comparison of the pre- and postoperative photographs of the root canal cross-sections enables the evaluation of the most important requirements of root canal preparation, i.e. the prepared canal completely includes the original canal and no unprepared areas are left.

The results for postoperative cross-sections are comparable to those obtained for Quantec SC and HERO 642 and for ProFile .04 and Lightspeed in recent studies (Hülsmann *et al.* 2001, Versümer *et al.* 2002). In the majority of specimens, round or oval cross-sections were found with no differences between the two systems.

Although not statistically significant, the number of specimens showing no or only minimal contact between pre- and postoperative cross-section was higher after HERO 642 preparation than following the use of FlexMaster. Good results concerning postoperative cross-sections have been described already for HERO 642 (Schäfer & Fritzenschaft 1999) and FlexMaster (Schäfer & Lohmann 2002a). The results for HERO 642 were clearly better than in a previous study using the same study design (Hülsmann *et al.* 2001). This will mainly be as a result of the fact that the final preparation size was 45 in the present study, but only 40 in the previous one. This highlights the fact that a preparation size larger than 40 may be necessary in many cases in order to contact as much of the circumference of the root canal as possible but on the other hand, may result in a small but measurable higher degree of apical straightening. Nevertheless, in both groups many specimens showed unprepared root canal areas.

Cleaning ability

As the majority of investigations on Ni–Ti instruments have focused on preparation form and working safety, there are only few studies reporting on the cleaning ability of such systems, although this should be regarded as of major interest.

In their SEM study on extracted human teeth, Schäfer & Lohmann (2002b) used the same indices for remaining debris and smear layer as in the present study. Following preparation with FlexMaster, they found significantly more debris and smear layer than those after manual preparation with K-Flexofiles, although these differences were not significant for the middle and apical thirds of the root canals. They discovered uninstrumented areas with remaining debris in all areas of the canals irrespective of the preparation technique, with the worst results for the apical third. This is in agreement with the results of the present study and several earlier studies on post-preparation cleanliness (Hülsmann *et al.* 1997; 2001, Schäfer & Zapke 2000, Versümer *et al.* 2002). These findings 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. Compared to results of a similar study using ProFile Ni–Ti files, Schäfer & Lohmann (2002b) found FlexMaster to be superior to ProFile in terms of debris removal and concluded that different rotary Ni–Ti systems vary in their debris removal efficiency, which may result from differing flute designs. The comparison of previous studies on instruments with and without radial lands (ProFile, Lightspeed, HERO 642) (Hülsmann *et al.* 2001, Versümer *et al.* 2002) confirms these findings.

Working safety

High numbers of instrument fractures have been reported for Ni–Ti files in several earlier studies (Kavanagh & Lumley 1998, Baumann & Roth 1999, Schäfer & Fritzenschaft 1999), indicating that Ni–Ti instruments may be more susceptible to separation than conventional stainless steel instruments. Baumann & Roth (1999) reported that the incidence of fractures increased with increasing size of the files, with most fractures occuring with size 30 and 35 files. In a study on HERO 642 instruments using simulated root canals with varying curvatures, Schäfer & Fritzenschaft (1999) found instrument fractures in 4.2% of the simulated canals with a 28° curvature and 8.3% canals with a 35° curvature. In the present study, HERO 642 proved

to be a safe system with no procedural accidents such as file fractures, apical blockages or even perforations. This confirms the results of a recent investigation on HERO 642 using the same study design in which no fracture and no loss of working length, but three apical blockages were observed (Hülsmann *et al.* 2001). With FlexMaster, one file separated but further accidents were not recorded. The relatively low incidence of instrument fractures may be related to the convex or triangular instrument cross-section of the two systems which results in a more massive core of the files when compared to u-shaped cross-sections as present in other Ni–Ti systems. Schäfer & Fritzenschaft (1999) reported 14 fractures of ProFile .06 and .04 instruments during instrumentation of 48 simulated root canals with different types of curvature, but only three fractures of HERO 642 instruments, which might confirm the relevance of a massive instrument core in the prevention of instrument fractures. Thompson & Dummer (2000a) for HERO 642 reported two fractures and eight cases of instrument deformation during preparation of 40 simulated root canals with different types of curvature. Apical blockages or cases of loss of working length did not occur in their study. Weiger *et al.* (2002) experienced two fractures of FlexMaster instruments during preparation of 45 curved root canals, Schäfer & Lohmann (2002a) reported two fractures and 15 instrument deformations during preparation of 96 simulated root canals with different types of curvature. Summarizing all the published studies, a good working safety of HERO 642 is obvious. The same seems to be true for FlexMaster, although only three studies on this system have been published. Nevertheless, following the proposal of Gambarini (2000), the use of a low-torque motor might further reduce the risk of instrument fractures.

Working time

The good results for HERO 642 are confirmed by the study of Schäfer & Fritzenschaft (1999) who found a significantly shorter working time for HERO 642 than for the ProFile instruments. In the studies of Thompson & Dummer (1997a; 1998a) and Bryant *et al.* (1998a), HERO 642 has been reported to need more working time than Ni–Ti instruments with different design features such as ProFile, Quantec SC or Lightspeed. In other studies, preparations using HERO 642 instruments could be completed faster than those using ProFile (Schäfer & Fritzenschaft 1999) or Quantec SC (Hülsmann *et al.* 2001), which may be related to the negative cutting angle of the flutes resulting in a higher cutting efficiency. HERO 642 and FlexMaster needed significantly less working time than K-Flexofile hand instruments (Schäfer & Fritzenschaft 1999, Schäfer & Lohmann 2002a).

Although there was a slight difference in the number of instruments used, the difference in mean working time in the present study was not significant; with both systems, preparations could be completed in an acceptable preparation time of about 1 min per root canal. The mean working time per instrument was nearly identical for both systems (7.2 s for HERO 642, 7.1 s for FlexMaster). Both systems performed more rapidly than Quantec SC (Hülsmann *et al.* 2001, Herbst 2002), Lightspeed (Herbst 2002, Versümer *et al.* 2002) or ProFile .04 (Versümer *et al.* 2002), which again might be because of the superior cutting ability of the instruments when compared to those 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 of such systems. Under the limitations of the present study, no differences in terms of straightening root canal curvature, centring ability, working safety, working time and cleaning ability could be found between the two Ni–Ti systems HERO 642 and FlexMaster. Both systems showed some deficiencies in terms of debridement leaving smear layer on the root canal walls in the majority of cases.

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