Influence of different types of automated devices on the shaping ability of rotary nickel-titanium FlexMaster instruments

E. Schäfer, M. Erler & T. Dammaschke
Department of Operative Dentistry, University of Münster, Münster, Germany

Abstract

Schäfer E, Erler M, Dammaschke T. Influence of different types of automated devices on the shaping ability of rotary nickel-titanium FlexMaster instruments. *International Endodontic Journal*, **38**, 627–636, 2005.

Aim To compare the shaping ability of rotary FlexMaster nickel-titanium instruments in simulated curved canals and in curved canals of extracted teeth when set into permanent rotation with three different torque-limited automated devices.

Methodology Root canal instrumentation was performed with three different torque-limited automated devices (ENDOadvance, SIRONiTi and Endo IT motor) by FlexMaster nickel-titanium instruments up to size 35. *Simulated canals*: 28° and 35° curved canals in resin blocks ($n = 20$ canals in each group) were prepared. Pre- and post-instrumentation images were recorded and assessment of canal shape was completed with a computer image analysis program. *Extracted teeth*: A total of 60 curved root canals were divided into three groups, which were balanced with respect to the angle and the radius of canal curvature. Straightening of the canal curvatures was determined with a computer image analysis program. Incidence of canal aberrations, preparation time, changes of working length and instrument failures were recorded both in simulated and real canals.

Results In simulated and real canals, instrumentation with Endo IT was significantly faster than with SIRONiTi ($P < 0.05$). With respect to canal aberrations in simulated canals, there were no significant differences between the devices ($P > 0.05$), even though more aberrations were created with ENDOadvance and SIRONiTi. In real canals, the Endo IT motor resulted in significantly less straightening during instrumentation ($P < 0.05$) than SIRONiTi. A total of three instruments separated (one file in each group) during the enlargement of 35° curved simulated canals. All systems maintained working distance well.

Conclusions All systems respected original root canal curvature well and were safe, indicating that torque-limited rotation handpieces are suitable for preparing curved root canals.

Keywords: canal curvature, canal straightening, canal transportation, curved root canals, nickel-titanium, resin blocks, root canal preparation, rotary instruments.

Received 24 January 2005; accepted 21 April 2005

Introduction

The unique metallurgical properties of nickel-titanium have made it possible to develop relatively safe rotary instruments. Several studies confirmed the ability of rotary nickel-titanium instruments to maintain the shape of even severely curved canals. Furthermore, in most of these studies it has been pointed out that canal enlargement was significantly faster with rotary nickel-titanium instruments compared with hand preparation (Thompson & Dummer 1997a,b,c, 2000a, Kum *et al.* 2000, Schäfer & Lohmann 2002a,b). However, other aspects of root canal preparation with rotary nickel-titanium instruments are still controversial (Schäfer 1998, Thompson 2000), such as their increased risk of

---

Correspondence: Prof. Dr Edgar Schäfer, Department of Operative Dentistry, Waldeyerstr. 30, D-48149 Münster, Germany (Fax: + 49 251 834 70 37; e-mail: eschaef@uni-muenster.de).

instrument fracture (Gambarini 2000, 2001b, Schäfer & Vlassis 2004b).

Therefore, in order to minimize the risk of intracanal breakage of nickel-titanium root canal instruments, several automated devices have been developed, such as different types of electric torque control motors (Gambarini 2000, 2001a,b) and torque-limited rotation handpieces (Schäfer & Zapke 2000, Fariniuk *et al.* 2001, Dammaschke & Schäfer 2004, Gerbert & Hülsmann 2004). Different types of torque control motors are used in conjunction with nickel-titanium instruments (Gambarini 2000, Yared & Sleiman 2001, Yared *et al.* 2003, Yared & Kulkarni 2004). When a high-torque control motor is used, the instrument is very effective but the incidence of file deformation and separation tends to increase (Yared *et al.* 2003). The torque at failure is often exceeded with this type of motors (Gambarini 2000, Yared *et al.* 2003). Contrarily, low-torque control motors, which have been introduced more recently, should allow the operator to set torque at levels (<1 N cm) below the estimated torque at failure (Yared *et al.* 2003). These motors will reverse the rotation of the file when the instrument is subjected to stress levels equal to the present torque value (Yared *et al.* 2003). It has been shown that low-torque control motors reduced the cyclic fatigue of nickel-titanium instruments better than a high-torque control motor (Gambarini 2001a,b). The Endo IT motor (VDW, Munich, Germany) is an exponent of these low-torque control motors.

Besides these electric torque control motors some attempts have been made to develop different torque-limited rotation handpieces. The predecessor of these handpieces was the ENDOflash (KaVo, Biberach, Germany) with an integrated mechanical torque control. In the middle of the handpiece is a swivel type adjustment ring which permits the selection of three different, colour-coded torque settings (Schäfer & Zapke 2000). According to several previous reports (Fariniuk *et al.* 2001, Dammaschke & Schäfer 2004, Gerbert & Hülsmann 2004), the ENDOflash handpiece offered good results in root canal preparation when used with nickel-titanium files. Most recently, the ENDOadvance (KaVo) handpiece is available as a succeeding model. According to the manufacturer's instructions, 40 000 rpm is the maximum speed of the handpiece. Due to a 120 : 1 reduction each file is then rotating with a speed of 333 rpm. Four different torque settings can be adjusted: level 1 = 0.25 N cm; level 2 = 0.50 N cm; level 3 = 1.00 N cm; and level 4 = 3.00 N cm. An integrated glide clutch can stop the rotation of the file if the recommended torque is reached. As soon as the glide clutch is activated a clicking sound is audible and a vibration is noticeable (Dammaschke & Schäfer 2004). A second recently introduced torque-limited rotation handpiece is the SIRONiTi contra-angle handpiece (Sirona, Bensheim, Germany). Due to a 115 : 1 reduction the maximum speed is set at 350 rpm. The five different torque settings (settings ranging between 1 and 3 N cm) can be selected with a turning ring. Several torque cards are available with the torque levels recommended for the file assortment of different manufacturers.

As the rotary nickel-titanium FlexMaster instruments have recently been reported to allow a rapid and well centred canal preparation (Schäfer & Lohmann 2002a,b, Hübscher *et al.* 2003, Hülsmann *et al.* 2003, Weiger *et al.* 2003) these instruments were used with different automated devices in the present study.

The aim of this study was therefore to investigate the influence of different automated devices (ENDOadvance and SIRONiTi handpieces and Endo IT motor) on the shaping ability of FlexMaster instruments in simulated curved canals in resin blocks and in extracted human teeth with curved root canals.

Materials and methods

Automated devices and root canal instruments

In the first group the ENDOadvance handpiece was used to set the FlexMaster instruments into permanent rotation at a speed of 333 rpm.

In the second group the instruments were set into permanent rotation with the torque-limited rotation SIRONiTi handpiece at a maximum speed of 350 rpm. Of the five different torque settings which can be selected with a turning ring only the settings 1 and 2 were used in this study (Table 1).

In the third group the instruments were set into permanent rotation with a 4 : 1 reduction handpiece (WD-66 EM; W & H, Buermoos, Austria) powered by a torque-limited electric motor (Endo IT motor). For each file the individual torque limit and rotational speed programmed in the file library of the Endo IT motor were used.

In all of these three groups, nickel-titanium FlexMaster instruments (VDW) were used. The different tapers and sizes used are listed in Table 1.

Table 1 Instrumentation sequence and torque settings with the three different automated devices

Instrument no.	Taper/ size	Working length Simulated canals	 Extracted teeth	ENDOadvance (N cm)	SIRONiTi	Endo IT (N cm)
1	.06/20	5 mm	1/2 length	0.5	Setting 1	0.65
2	.04/30	9 mm	2/3 length	1	Setting 2	0.86
3	.04/25	11 mm	3/4 length	0.5	Setting 1	0.58
4	.04/20	Full length of the canal		0.5	Setting 1	0.35
5	.02/20	Full length of the canal		0.25	Setting 1	0.18
6	.02/25	Full length of the canal		0.25	Setting 1	0.38
7	.02/30	Full length of the canal		0.5	Setting 1	0.51
8	.02/35	Full length of the canal		1	Setting 2	0.74

Simulated canals

Simulated canals made of clear polyester resin (Viapal uP 004/64; Vianova Resins, Hamburg, Germany) with coloured canal walls were used to assess instrumentation. The degree of curvature was either 28° or 35°. The diameter and the taper of all simulated canals were equivalent to an ISO standard size 15 root canal instrument. The 28° canals were 13 mm long, the straight part being 5.5 mm and the curved part 7.5 mm. The curvature was defined mathematically with a radius of 7.5 mm resulting in an angle of 28° according to the Schneider (1971) method. The 35° canals were 13 mm long, the straight part being 5 mm and the curved part 8 mm. The radius of the curvature was 6.5 mm.

Instrumentation

The transparent blocks were covered with adhesive tape during the preparation phase. All instruments were used to enlarge four canals only. Prior to use, each instrument was coated with glycerine to act as a lubricant, and copious irrigation with water was performed repeatedly after every instrument. All canals were enlarged by an operator experienced in the automated preparation with FlexMaster instruments. Measurements of the canals were carried out by a second examiner who was blinded in respect of all experimental groups. A randomly laid down sequence was used to avoid bias towards one of the three devices. Only six resin blocks (three with 28° curves and three with 35° curves) were instrumented at a time to minimize operator fatigue and familiarity. These six resin blocks were defined as a set. The order of use of the three devices within a set was rotated.

All canals were enlarged to an apical size 35. The instrumentation sequence used with all automated devices and the selected torque settings are given in Table 1. The preparation sequence was slightly modified from that recommended by the manufacturer, because in a pilot study the described instrumentation sequence allowed preparation of the different canals without difficulties. Once the instrument had negotiated to the end of the canal and had rotated freely, it was removed.

In each of these three groups, 20 canals with 28° and 20 canals with 35° curves were enlarged. Thus, a total of 120 canals were prepared.

Assessment of canal preparation and analysis of data

The time for canal preparation was recorded and included total active instrumentation, instrument changes within the described instrumentation sequence and irrigation. Changes of working length were determined by subtracting the final length (measured to the nearest 0.5 mm) of each canal after preparation from the original length (13 mm). The preparation time and the loss of working length were statistically analysed using analysis of variance (ANOVA) and *post-hoc* Student–Newman–Keuls test at a significance level of $P < 0.05$. The number of fractured and permanently deformed instruments during enlargement was also recorded. A chi-square test was used to determine whether there were significant differences between the three automated devices concerning instrument failure and deformation of instruments.

The assessment of preparation shape was carried out with the computer program Image 1.41 (National Institutes of Health public domain program). Therefore, pre- and post-instrumentation canal shapes were taken in a standardized manner and magnified 40 times by means of a charged coupled device (CCD) camera (SSC-M370CE; Sony Corporation, Tokyo, Japan) and stored in a computer (Macintosh Quadra 660 AV; Apple Computer, Ismaning, Germany). Thereafter, a composite image was produced of the pre- and post-instrumentation images and superimposed. The amount of resin removed, e.g. the difference between the canal configurations before and after instrumentation was determined both for the inner and the outer side of the curvature in 1 mm steps using the Image 1.41 program. The amount of resin substance removed in all canals was measured one-dimensionally with a precision of ±0.01 mm. The first measuring point was 1 mm away from the apical ending of the canal, the last measuring point was 10 mm from the apical end, resulting in 10 measuring points at the outer and 10 points at the inner side of the canal, and thus, in a total of 20 measuring points (Schäfer *et al.* 1995). All measurements were made at right angles to the surface of the canal. The data were analysed by using ANOVA and *post-hoc* Student–Newman–Keuls test for all pairwise comparisons at a significance level of $P < 0.05$.

Furthermore, based on the superimposition of pre- and postoperative images, assessments were made according to the presence of different types of canal aberrations, such as apical zip associated with elbow, ledge and perforation. These different types of canal aberration were defined according to the detailed descriptions published previously (Thompson & Dummer 2000b).

Extracted teeth

A total of 60 extracted human teeth with at least one curved root and curved root canal were selected for this investigation. Coronal access was achieved using diamond burs and the canals were controlled for apical patency with a root canal instrument of size 10. Only teeth with intact root apices, and whose root canal width near the apex was approximately compatible with size 15 were included. This was checked with silver point sizes 15 and 20 (VDW).

Standardized radiographs were taken prior to the instrumentation with the initial root canal instrument of size 15 inserted into the curved canal. The tooth was placed in a radiographic mount made of silicone-based impression material (Silaplast Futur; Detax, Ettlingen, Germany) to maintain a constant position. The radiographic mount comprised a radiographic paralleling device embedded in acrylic resin. This device was attached to a Kodak Ultra-speed film (Kodak, Stuttgart, Germany) and was aligned so that the long axis of the root canal was parallel and as near as possible to the surface of the film. The X-ray tube, and thus, the central X-ray beam was aligned perpendicular to the root canal. The exposure time (0.12 s; 70 kV, 7 mA) was the same for all radiographs with a constant source-to-film distance of 50 cm and an object-to-film distance of 5 mm. The films were developed, fixed, and dried in an automatic processor (Dürr-Dental XR 24 Nova; Dürr, Bietigheim-Bissingen, Germany).

The degree and the radius of canal curvature were determined using a computerized digital image processing system (Schäfer *et al.* 2002). Only teeth whose radii of curvature ranged between 5.0 and 9 mm and whose angles of curvature ranged between 25° and 35° were included (Table 2). On the basis of the degree and the radius of curvature the teeth were allocated into three identical groups of 20 teeth. The homogeneity of the three groups with respect to the degree and the radius of curvature was assessed using ANOVA and *post-hoc* Student–Newman–Keuls test (Table 2). At the end of canal preparation, the canal curvatures were redetermined on the basis of a radiograph with the final root canal instrument inserted into the canal using the same technique (Schäfer *et al.* 2002) in order to compare the initial curvatures with those after instrumentation. Only one canal was instrumented in each tooth.

Root canal instrumentation

The working length was obtained by measuring the length of the initial instrument (size 10) at the apical foramen minus 1 mm. Instruments were used to enlarge four canals only. The canals of all teeth were prepared with instruments up to size 35. After each instrument, the root canal was flushed with 5 mL of a 2.5% NaOCl solution and at the end of instrumentation

Table 2 Extracted teeth: characteristics of curved root canals ($n = 20$ teeth per group)

	Curvature (°)			Radius (mm)		
Instrument	Mean ± SD	Min	Max	Mean ± SD	Min	Max
ENDOadvance	29.70 ± 3.41	25.0	35.0	6.64 ± 0.93	5.5	8.6
SIRONiTi	29.65 ± 3.18	25.2	35.0	6.66 ± 1.12	5.2	8.5
Endo IT	29.60 ± 3.20	25.6	35.0	6.53 ± 1.07	5.0	8.8
P-value (ANOVA)	0.995			0.920		

Table 3 Simulated curved canals: number of fractured and permanently deformed instruments

Device	28° curved canals		35° curved canals	
	Fractured	Deformed	Fractured	Deformed
ENDOadvance	0	1	1	1
SIRONiTi	0	0	1	2
Endo IT	0	0	1	2

with 5 mL of NaCl using a plastic syringe with a closed-end needle (Hawe Max-I-probe; Kerr-Hawe, Bioggio, Switzerland). The needle was inserted as deep as possible into the root canal without binding.

The preparation sequences were the same as described above for the preparation of simulated canals in resin blocks (Table 1).

Evaluations

All root canal preparations were completed by one operator whilst the assessment of the canal curvatures prior to and after instrumentation were carried out by a second examiner who was blind in respect of all experimental groups.

Based on the canal curvatures assessed prior to and after instrumentation, canal straightening was determined as the difference between canal curvature prior to and after instrumentation. An ANOVA and *post-hoc* Student–Newman–Keuls test were used for comparisons of the three groups. The level of statistical significance was set at $P < 0.05$.

The time for canal preparation was recorded and included total active instrumentation, instrument changes within the sequence and irrigation. The change of working length was determined by subtracting the final length (measured to the nearest 0.5 mm) of each canal after preparation from the original length. The preparation time and the loss of working length were statistically analysed using the ANOVA and *post-hoc* Student–Newman–Keuls test at a significance level of $P < 0.05$. The number of fractured and permanently deformed instruments during enlargement was also recorded. A chi-square test was used to determine whether there were significant differences between the three devices.

Results

Simulated curved canals

During preparation of the 120 canals, a total of three instruments separated. Therefore, the following results are based on the remaining 117 canals. Three canals with 35° curves were excluded.

Instrument failure

Table 3 details the number of deformations and fractures of instruments that occurred during the study. In the 28° curved canals no fracture of the FlexMaster instruments occurred but in the 35° curved canals three instruments (.02 taper size 20, .02 taper size 30, and .04 taper size 30; all used for the third canal) fractured. The number of fractured instruments ($P = 1.0$) and the number of permanently deformed instruments (28° curved canals: $P = 0.365$; 35° curved canals: $P = 0.812$) was not significantly different between the groups.

Preparation time

The mean time taken to prepare the canals with the different automated devices is shown in Table 4. Both in 28° and 35° curved canals, instrumentation with the Endo IT motor was significantly faster than with ENDOadvance or SIRONiTi ($P < 0.05$). Independent of the curvature of the canals, preparation with ENDOadvance was significantly faster than with SIRONiTi ($P < 0.05$).

Change of working length

All canals remained patent following instrumentation, thus, none of the canals became blocked with resin debris. None of the canals had overextension of preparation, whereas a loss of working distance was found in several canals.

The mean loss of working length that occurred with the different automated devices is listed in Table 5. The differences between the three devices were not statistically significant, neither in the 28° curved ($P = 0.758$) nor in the 35° curved canals ($P = 0.875$).

Table 4 Simulated curved canals: mean preparation time (min) and SD with the different automated devices

Device	28° curved canals		35° curved canals	
	Mean	SD	Mean	SD
ENDOadvance	9.61	0.71	8.80	0.56
SIRONiTi	10.58	1.04	10.59	1.10
Endo IT	5.70	0.57	6.17	0.78

Table 5 Simulated curved canals: mean loss of working length (mm) and SD with the different automated devices

	28° curved canals		35° curved canals	
Device	Mean	SD	Mean	SD
ENDOadvance	0.30	0.38	0.17	0.29
SIRONiTi	0.23	0.37	0.21	0.33
Endo IT	0.22	0.34	0.16	0.27

Canal shapes

The results concerning the assessment of canal aberrations are summarized in Table 6. With respect to the different types of aberrations evaluated, both in canals with 28° and with 35° curves, there were no significant differences between the three different devices (chi-square test, $P > 0.05$), even though more zips and more ledges were created with ENDOadvance and SIRONiTi than with the Endo IT motor. Also with regard to the total number of aberrations there were no significant differences between the devices (chi-square test, $P > 0.05$).

On average, in the canals with 28° curves, the instruments set into rotation with the Endo IT motor removed material evenly on the outer, as well as on the inner side of curvature. At 14 of 20 measuring points, significant differences ($P < 0.05$) occurred between resin removal achieved with the three devices (Table 7). In general, the canals prepared with the different devices remained well centred.

In the canals with 35° curves, on average, only limited differences were found between the three devices (Table 8). ENDOadvance and SIRONiTi created minimal transportation towards the outer aspect of the curve (Fig. 1a,b) and in some cases a coronal narrowing (Fig. 1a). Only at five of 20 measuring points, significant differences ($P < 0.05$) occurred between resin removal achieved with the three devices.

Extracted teeth

During preparation of the 60 canals no instrument separated and no instrument was permanently deformed.

Instrumentation results

The mean time taken to prepare the canals with the different automated devices is shown in Table 9. Instrumentation with the Endo IT motor or with ENDOadvance was significantly faster than with SIRONiTi ($P < 0.05$).

All canals remained patent following instrumentation, thus, none of the canals were blocked with dentine. With all automated devices, no canal had

Table 6 Simulated curved canals: incidence of canal aberrations by automated devices

	28° curved canals			35° curved canals		
Aberration type	ENDOadvance	SIRONiTi	Endo IT	ENDOadvance	SIRONiTi	Endo IT
Zip/elbow	3	3	1	4	4	1
Ledge	3	2	1	4	3	1
Perforation	0	0	0	0	0	0

Chi-square test, no significant differences ($P > 0.05$).

Table 7 Simulated curved canals: mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 28° curved canals

	Inner canal wall (mm from the apex)										Outer canal wall (mm from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
ENDOadvance																				
Mean	0.04	0.06	0.08	0.17	0.20	0.24	0.30	0.33	0.31	0.25	0.10	0.14	0.16	0.16	0.14	0.10	0.07	0.07	0.07	0.07
SD	0.03	0.04	0.06	0.08	0.08	0.09	0.11	0.12	0.11	0.10	0.06	0.08	0.08	0.09	0.09	0.08	0.06	0.05	0.05	0.06
SIRONiTi																				
Mean	0.03	0.04	0.06	0.07	0.11	0.17	0.21	0.25	0.23	0.16	0.11	0.17	0.19	0.20	0.18	0.13	0.07	0.04	0.04	0.04
SD	0.02	0.04	0.05	0.07	0.09	0.09	0.10	0.10	0.10	0.08	0.05	0.06	0.05	0.06	0.06	0.07	0.05	0.04	0.05	0.04
Endo IT																				
Mean	0.04	0.04	0.06	0.07	0.10	0.15	0.19	0.23	0.22	0.17	0.11	0.17	0.20	0.21	0.23	0.22	0.19	0.13	0.12	0.15
SD	0.02	0.02	0.04	0.04	0.07	0.08	0.09	0.10	0.10	0.09	0.05	0.04	0.05	0.06	0.07	0.09	0.09	0.09	0.08	0.09
P-value	0.290	0.129	0.278	**	**	**	**	**	**	*	0.768	0.319	0.211	*	**	**	**	***	**	**

*$P < 0.05$; **$P < 0.01$.

Table 8 Simulated curved canals: mean material removed (mm) and SD at the different measuring points after instrumentation of simulated 35° curved canals

	Inner canal wall (mm from the apex)										Outer canal wall (mm from the apex)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
ENDOadvance																				
Mean	0.05	0.06	0.08	0.14	0.20	0.24	0.28	0.29	0.25	0.21	0.17	0.19	0.21	0.22	0.22	0.16	0.11	0.07	0.07	0.07
SD	0.06	0.08	0.07	0.10	0.14	0.14	0.15	0.15	0.14	0.14	0.06	0.07	0.09	0.10	0.10	0.10	0.08	0.06	0.06	0.06
SIRONiTi																				
Mean	0.04	0.06	0.08	0.10	0.14	0.16	0.26	0.29	0.28	0.25	0.14	0.16	0.16	0.16	0.17	0.14	0.10	0.07	0.06	0.06
SD	0.03	0.05	0.07	0.09	0.09	0.11	0.10	0.09	0.10	0.11	0.07	0.09	0.10	0.11	0.12	0.12	0.10	0.09	0.07	0.07
Endo IT																				
Mean	0.04	0.04	0.06	0.09	0.12	0.14	0.21	0.26	0.24	0.20	0.18	0.17	0.19	0.20	0.23	0.24	0.20	0.14	0.13	0.14
SD	0.03	0.05	0.05	0.07	0.10	0.10	0.13	0.11	0.12	0.11	0.06	0.06	0.05	0.04	0.05	0.06	0.06	0.07	0.07	0.05
P-value	0.618	0.546	0.589	0.181	0.065	0.070	0.253	0.648	0.716	0.460	0.066	0.534	0.187	0.113	0.225	*	*	*	**	**

*$P < 0.05$; **$P < 0.01$.

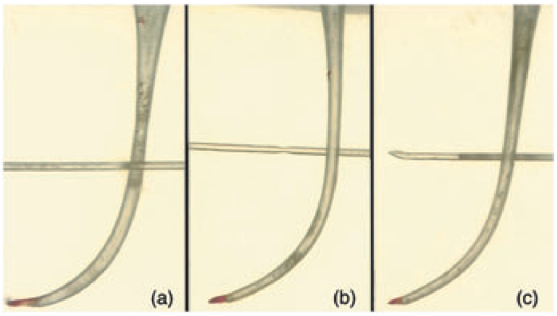

Figure 1 Representative examples of canal shapes of 35° curved canals as the result of instrumentation with FlexMaster instruments set into rotation by (a) ENDOadvance, (b) SIRONiTi and (c) Endo IT. Notice the sections of red coloured canal walls indicating that nearly no resin has been removed on this canal wall areas.

overextension of preparation, whereas a loss of working distance was found in several cases. The mean changes of working length that occurred with the different devices are listed in Table 9. The differences between the three devices were not statistically significant ($P = 0.418$).

Table 9 Extracted teeth: mean preparation time (min) and SD and mean changes of working distance (mm) and SD with the different automated devices

Instrument	Preparation time (min) Mean	SD	Working distance (mm) Mean	SD
ENDOadvance	3.99	1.00	−0.22	0.24
SIRONiTi	4.43	0.82	−0.32	0.27
Endo IT	3.83	0.52	−0.17	0.23

Table 10 Extracted teeth: mean degree of straightening of curved canals (°) and SD after canal preparation with the different automated devices ($n = 20$ canals in each group)

	Straightening (°)			
Instrument	Mean	SD	Min	Max
ENDOadvance	3.08	1.87	0	7.0
SIRONiTi	3.88	2.82	0	8.5
Endo IT	2.17	1.59	0	6.9

The mean straightening of the curved canals is shown in Table 10. The use of the Endo IT motor resulted in significantly less straightening (2.17°) during instrumentation ($P < 0.05$) compared with SIRONiTi (3.88°; Fig. 2). No significant differences ($P > 0.05$) were obtained between ENDOadvance and Endo IT and between ENDOadvance and SIRONiTi.

Discussion

The purpose of this study was to compare the shaping ability of rotary FlexMaster nickel-titanium instruments when set into permanent rotation with three different torque-limited automated devices.

This study described the shaping abilities of the instruments under strictly controlled laboratory conditions, using clear resin blocks. Use of simulated canals in resin blocks does not reflect the action of the instruments in root canals of real teeth. However, resin blocks allow a direct comparison of the shaping ability of different instruments (Schäfer *et al.* 1995). A major drawback of using rotary instruments in resin blocks is heat generated, which may soften the resin material (Kum *et al.* 2000) and lead to the binding of cutting blades, and separation of the instrument (Thompson &

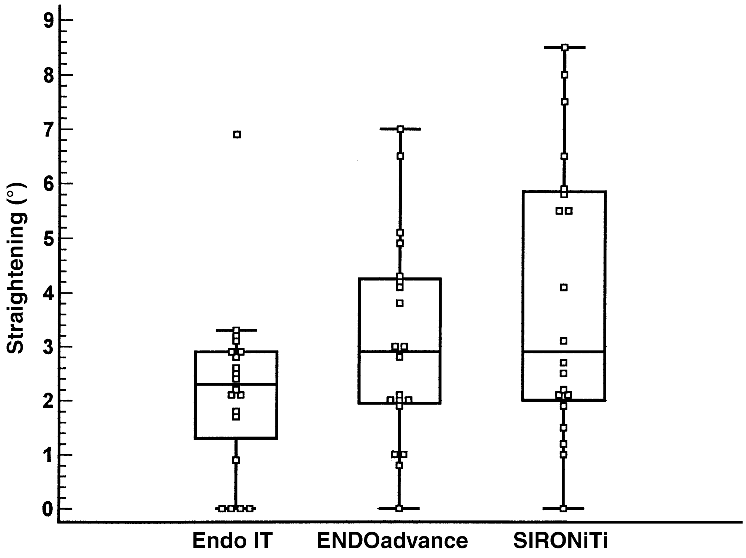

Figure 2 Straightening of the curved canals after preparation with the three different automated devices ($n = 20$ canals in each group): combined box-and-whisker and dot plot, each dot represents a reading of the difference between canal curvature prior to and after instrumentation.

Dummer 1997c, Baumann & Roth 1999). Therefore, in this study both simulated curved canals in resin blocks as well as curved canals in extracted human teeth were enlarged.

Despite the variations in the morphology of natural teeth, several attempts have been made to ensure standardization of the experimental groups. Therefore, the teeth in all experimental groups were balanced with respect to the apical diameter of the root canal and based on the initial radiograph the teeth were also balanced with respect to the angle and the radius of canal curvature. To achieve this a computerized digital image processing system was used to determine both the angle and the radius of curvature (Schäfer *et al.* 2002). The homogeneity of the three groups with respect to the defined constraints was examined using an ANOVA with *post-hoc* Student–Newman–Keuls test. According to the *P*-values obtained (Table 2), the groups were well balanced. The curvatures of all root canals ranged between 25° and 35° and the radii ranged between 5.0 and 8.8 mm (Table 2). Thus, the curvatures of the human root canals were comparable with those of the simulated canals in resin blocks, allowing a comparison of the results obtained in simulated and in human root canals.

With respect to the instrumentation results (different types of aberrations evaluated) in the simulated canals, no significant differences between the three different devices ($P > 0.05$; Table 6) were obtained. Both in canals with 28° and 35° curves, the original shape of curved canal was maintained well with all automated devices. Although there was a tendency for the Endo IT motor to create less canal aberrations and a more even material removal on the inner and the outer side of the canals (Fig. 1) these differences were not statistically significant. This tendency was more obvious in extracted teeth, as the use of the Endo IT motor resulted in significantly less straightening during instrumentation ($P < 0.05$) compared with SIRONiTi (Fig. 2). No significant differences ($P > 0.05$) were obtained between ENDOadvance and Endo IT and between ENDOadvance and SIRONiTi (Table 10).

These findings concerning the shaping ability of FlexMaster instruments when set into permanent rotation using the Endo IT motor are in agreement with several previous reports. In these studies using FlexMaster instruments with either high-torque motors with torque control (Schäfer & Lohmann 2002a,b, Hülsmann *et al.* 2003, Weiger *et al.* 2003) or with the low-torque Endo IT motor (Sonntag *et al.* 2003) maintenance of root canal curvature and centring ability of these systems was described both in extracted teeth (Schäfer & Lohmann 2002b, Hülsmann *et al.* 2003, Weiger *et al.* 2003) as well as in simulated curved canals (Schäfer & Lohmann 2002a, Sonntag *et al.* 2003).

In the present study, none of the canals became blocked with resin debris or dentine chips and none of the canals showed overextension of preparation. Thus, the only change of working length was a loss of working distance. In general, it was possible with all systems to control the working distance well (Tables 5 and 9). This finding is in agreement with several observations of other studies in that only small mean changes in working distance occurred with rotary nickel-titanium instruments (Kum *et al.* 2000, Thompson & Dummer 2000a, Schäfer & Vlassis 2004b). On the whole, it is questionable whether the small changes of working length observed in the present study have any clinical significance. These changes may be due to minor canal straightening during canal enlargement or lack of length control by the operator (Thompson & Dummer 2000a).

The mean time for canal preparation was recorded and included instrument changes within the described instrumentation sequences. Both in 28° and 35° curved simulated canals, instrumentation with the Endo IT motor was significantly faster than with ENDOadvance or SIRONiTi ($P < 0.05$, Table 4) and in root canals of real teeth instrumentation with Endo IT was significantly faster than with SIRONiTi ($P < 0.05$, Table 9). Thus, root canal preparation with an electric torque control motor seems to be faster than with torque-limited rotation handpieces. Nevertheless, both torque-limited rotation handpieces allowed a faster preparation of both simulated and real canals than some newer rotary nickel-titanium instruments (Schäfer & Vlassis 2004a,b). Thus, all devices tested in this study prepared curved canals relatively rapidly.

During the study, a total of three instruments separated (one in each group). All these instruments fractured during the enlargement of 35° curved simulated canals (Table 3). There was no statistically significant difference between the three devices ($P = 1.0$). It is worth emphasizing that all of these three instruments were used for the instrumentation of the third canal. Related to the total number of FlexMaster instruments used in each of the three experimental groups, a fracture rate of approximately 0.8% (one of 120 FlexMaster instruments used when all instruments were used to enlarge four canals) resulted. This separation rate is in agreement with previously reported fracture rates of newer rotary nickel-titanium instruments (Thompson & Dummer 1997a, 2000a, Baumann & Roth 1999, Kum *et al.* 2000, Schäfer & Vlassis 2004a,b).

Conclusions

Within the limitations of this study, FlexMaster instruments respected original canal curvature well and prepared curved canals rapidly without substantial change in working length when used with each of the three tested automated devices. The results indicate that torque-limited rotation handpieces were safe and are suitable for preparing curved root canals. Thus, these devices can be seen as an alternative to electric low-torque control motors.

References

Baumann MA, Roth A (1999) Effect of experience on quality of canal preparation with rotary nickel-titanium files. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **88**, 714–8.

Dammaschke T, Schäfer E (2004) Mechanical root canal preparation with the ENDOflash system – a review. *Acta Stomatologica Naissi* **20**, 261–74.

Fariniuk LF, Baratto-Filho F, Guerisoli DM, Barbizam JV, Pecora JD, Sousa-Neto MD (2001) Modelling capacity of ENDOflash files in simulated root canals. *Brazilian Dental Journal* **12**, 39–42.

Gambarini G (2000) Rationale for the use of low-torque endodontic motors in root canal instrumentation. *Endodontics and Dental Traumatology* **16**, 95–100.

Gambarini G (2001a) Cyclic fatigue of nickel-titanium rotary instruments after clinical use with low- and high-torque endodontic motors. *Journal of Endodontics* **27**, 772–4.

Gambarini G (2001b) Advantages and disadvantages of new torque-controlled endodontic motors and low-torque NiTi rotary instrumentation. *Australian Dental Journal* **27**, 99–104.

Gerbert C, Hülsmann M (2004) Comparative in-vitro study of different instruments for rotary preparation of the root canal system using the Endoflash device. *Deutsche zahnärztliche Zeitschrift* **59**, 387–92.

Hübscher W, Barbakow F, Peters OA (2003) Root-canal preparation with FlexMaster: canal shape analysed by micro-computed tomography. *International Endodontic Journal* **36**, 740–7.

Hülsmann M, Gressmann G, Schäfers F (2003) A comparative study of root canal preparation using FlexMaster and HERO 642 rotary Ni-Ti instruments. *International Endodontic Journal* **36**, 358–66.

Kum K-Y, Spångberg L, Cha BY, Il-Young J, Seung-Jong L, Chan-Young L (2000) Shaping ability of three ProFile rotary instrumentation techniques in simulated resin root canals. *Journal of Endodontics* **26**, 719–23.

Schäfer E (1998) Metallurgie und Eigenschaften von Nickel-Titan-Handinstrumenten. *Endodontie* **7**, 323–35.

Schäfer E, Lohmann D (2002a) Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile. Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal* **35**, 505–13.

Schäfer E, Lohmann D (2002b) Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile. Part 2. Cleaning effectiveness and instrumentation results in severely curved root canals of extracted teeth. *International Endodontic Journal* **35**, 514–21.

Schäfer E, Vlassis M (2004a) Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal* **37**, 229–38.

Schäfer E, Vlassis M (2004b) Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. *International Endodontic Journal* **37**, 239–48.

Schäfer E, Zapke K (2000) A comparative scanning electron microscopic investigation of the efficacy of manual and automated instrumentation of root canals. *Journal of Endodontics* **26**, 660–4.

Schäfer E, Tepel J, Hoppe W (1995) Properties of endodontic hand instruments used in rotary motion. Part 2. Instrumentation of curved canals. *Journal of Endodontics* **21**, 493–7.

Schäfer E, Diez C, Hoppe W, Tepel J (2002) Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. *Journal of Endodontics* **28**, 211–6.

Schneider SW (1971) A comparison of canal preparations in straight and curved canals. *Oral Surgery* **32**, 271–5.

Sonntag D, Delschen S, Stachniss V (2003) Root-canal shaping with manual and rotary Ni-Ti files performed by students. *International Endodontic Journal* **36**, 716–23.

Thompson SA (2000) An overview of nickel-titanium alloys used in dentistry. *International Endodontic Journal* **33**, 297–310.

Thompson SA, Dummer PMH (1997a) Shaping ability of NT engine and McXim rotary nickel-titanium instruments in simulated root canals: Part 1. *International Endodontic Journal* **30**, 262–9.

Thompson SA, Dummer PMH (1997b) Shaping ability of Lightspeed rotary nickel-titanium instruments in simulated root canals. Part 1. *Journal of Endodontics* **23**, 698–702.

Thompson SA, Dummer PMH (1997c) Shaping ability of ProFile.04 taper series 29 rotary nickel-titanium instruments in simulated canals. Part 1. *International Endodontic Journal* **30**, 1–7.

Thompson SA, Dummer PMH (2000a) Shaping ability of Hero 642 rotary nickel-titanium instruments in simulated root canals: Part 1. *International Endodontic Journal* **33**, 248–54.

Thompson SA, Dummer PMH (2000b) Shaping ability of Hero 642 rotary nickel-titanium instruments in simulated root canals: Part 2. *International Endodontic Journal* **33**, 255–61.

Weiger R, Brückner M, ElAyouti A, Löst C (2003) Preparation of curved root canals with rotary FlexMaster instruments compared to Lightspeed instruments and NiTi hand files. *International Endodontic Journal* **36**, 483–90.

Yared G, Kulkarni GK (2004) Accuracy of the DTC torque control motor for nickel-titanium rotary instruments. *International Endodontic Journal* **37**, 399–402.

Yared G, Sleiman P (2001) Failure with air, high torque control and low torque control motors. *International Endodontic Journal* **34**, 471–5.

Yared G, Bou Dagher F, Kulkarni K (2003) Influence of torque control motors and the operator's proficiency on ProTaper failures. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **96**, 229–33.