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Shaping ability and cleaning effectiveness of Mtwo versus coated and uncoated EasyShape instruments in severely curved root canals of extracted teeth

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Abstract

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Aim To compare the cleaning effectiveness and shaping ability of Mtwo, PVD-coated and uncoated EasyShape nickel–titanium rotary instruments during the preparation of curved root canals in extracted human teeth.

Methodology A total of 60 root canals of mandibular and maxillary molars with curvatures ranging between 25° and 35° were divided into three groups of 20 canals. Based on radiographs taken prior to instrumentation with the initial instrument inserted into the canal, the groups were balanced with respect to the angle and the radius of canal curvature. Canals were prepared using a low-torque control motor according the single-length technique. Using pre- and post-instrumentation radiographs, straightening of the canal curvatures was determined with a computer image analysis program. Preparation time, changes of working length and instrument failures were also recorded. These data were analysed statistically using ANOVA and Student–Newman–Keuls test. The amounts of debris and smear layer were quantified on the basis of a numerical evaluation scale. The data established for scoring the debris and the smear layer were recorded separately and analysed statistically using the Kruskal–Wallis test.

Results During preparation, one coated and two uncoated EasyShape files fractured. Completely clean root canals were never observed. All instruments maintained the original canal curvature well with no significant differences between the different instruments ($P > 0.05$). Instrumentation with Mtwo files was significantly faster than with the two other instruments ($P < 0.05$). For debris removal Mtwo instruments achieved significantly better results ($P < 0.001$) than the two EasyShape instruments. The use of coated EasyShape files resulted in significantly less debris compared to instrumentation with uncoated EasyShape instruments ($P < 0.05$). The results for remaining smear layer were similar and not significantly different for the coronal, middle and apical third of the canals ($P > 0.05$) but in summary significantly less smear layer was observed following instrumentation with Mtwo ($P < 0.01$).

Conclusions Under the conditions of this study, all instruments maintained the original canal curvature well. The use of Mtwo instruments resulted in good canal cleanliness. PVD-coating of EasyShape instruments had no impact on their shaping ability but improved their cleaning effectiveness.

Keywords: canal curvature, canal straightening, debris, PVD-coating, single length technique, smear layer.

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Introduction

Chemo-mechanical instrumentation of the root canal system results in significant reduction of microorganisms

(Hülsmann *et al.* 2005, Averbach & Kleier 2006) and is thus essential for successful root canal treatment. This includes the removal of the infected dentine and organic tissue by shaping and dissolution. Several studies have assessed the cleaning ability of different root canal instruments and proved that currently no instrument can predictably clean the entire root canal system (Usman *et al.* 2004, Haapasalo *et al.* 2005, Paqué *et al.* 2009, Fornari *et al.* 2010).

Rotary nickel–titanium instruments have been shown to be well suited to prepare even severely curved root canals (Hülsmann *et al.* 2005, Versiani *et al.* 2008, Pasternak-Junior *et al.* 2009). To evaluate the shaping abilities of root canal instruments standardized canal models in resin blocks are an ideal experimental model but the extrapolation of the obtained results to the clinical situation should be exercised with care (Ayar & Love 2004, Hülsmann *et al.* 2005, Schäfer & Dammaschke 2009). Therefore, studies using real root canals in extracted teeth are required in order to fully assess the effectiveness of root canal instruments. To date, several studies have reported clean and debris-free dentine surfaces in the coronal and middle thirds of canals, whereas in the apical portion increasing amounts of debris were constantly found using rotary instruments (Wu & Wesselink 1995, Hülsmann *et al.* 1997, 2003, Ahlquist *et al.* 2001, Gambarini & Laszkiewicz 2002, Schäfer & Schlingemann 2003, Foschi *et al.* 2004, Schäfer & Vlassis 2004, Paqué *et al.* 2005). In general, there are some indications that the flute design of rotary nickel–titanium files is a key factor in respect of their cleaning efficiency. According to some recent reports, instruments with sharp cutting edges seem to be superior to those having radial lands in cleaning the root canal (Jeon *et al.* 2003, Schäfer & Vlassis 2004, Hülsmann *et al.* 2005, Kuzekanani *et al.* 2009).

Rotary nickel–titanium Mtwo files (VDW, Munich, Germany) showed satisfying results in cleaning and shaping of even severely curved root canals (Schäfer & Vlassis 2004, Schäfer *et al.* 2006). These instruments are characterized by an S-shaped cross sectional design with a non-cutting tip. The two cutting edges have a positive rake angle to cut dentine effectively. Moreover, the pitch length increases from the tip to the shaft. This design is claimed to eliminate threading and binding in continuous rotation, and to reduce transportation of debris towards the apex.

The cross sectional design of the newer rotary nickel–titanium EasyShape files (Brasseler, Lemgo, Germany) is similar to that of the Mtwo files. Hence it can be assumed that this system may have comparable properties. As for the Mtwo system, the EasyShape instruments are also used according to the single-length technique. The commercially available EasyShape instruments are physical vapour deposition-coated (PVD-coated) with a thin layer of TiN in order to increase their surface hardness. Studies on the influence of PVD-coatings have shown that the cutting efficiency of PVD-coated nickel–titanium files was increased by up to 26% in comparison with uncoated instruments (Schäfer 2002). Further details regarding the physical background of PVD-coating can be found in a previous paper (Schäfer 2002).

The aim of this investigation was to compare the shaping ability (straightening of curved root canals, preparation time, loss of working distance, incidence of instrument separation) and the cleaning efficacy (residual debris, quality of the smear layer) after preparation of severely curved root canals in extracted teeth using Mtwo and PVD-coated as well as uncoated EasyShape instruments.

Materials and methods

Extracted teeth

A total of 60 extracted human teeth with at least one curved root and curved root canal were selected. Coronal access was achieved using diamond burs and the canals were controlled for apical patency with a size 10 root canal instrument. 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 points sizes 15 and 20 (VDW, Munich, Germany).

Standardized radiographs were taken prior to canal instrumentation with the initial 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 compromised of 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 4.0 and 8.5 mm and whose angles of curvature ranged between 25° and 35° were included (Table 1). 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 analysis of variance (ANOVA) and post-hoc Student–Newman–Keuls test (Table 1). 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. After each instrument, the root canal was flushed with 5 mL of a 2.5% NaOCl solution and at the end of instrumentation 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 deeply as possible into the root canal without binding.

All types of 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; VDW, Munich, Germany). For each file the individual torque limit programmed in the file library of the Endo IT motor was used. Rotational speed was set at 300 rpm for all instruments. The preparation sequences were as follows:

Group A: All Mtwo instruments were used to the full length of the canals (single-length technique) according to the manufacturer's instructions using a gentle in-and-out motion. The instrumentation sequence was:

1. A 0.04 taper size 10 instrument.
2. A 0.05 taper size 15 instrument.
3. A 0.06 taper size 20 instrument.
4. A 0.06 taper size 25 instrument.
5. A 0.05 taper size 30 instrument.
6. A 0.04 taper size 35 instrument.

Once, the instrument had negotiated to the end of the canal and had rotated freely, it was removed.

Groups B and C: Both uncoated and coated EasyShape instruments were used to the full length of the canals (single-length technique) according to the manufacturer's instructions using a gentle in-and-out motion. The instrumentation sequence was:

1. A size 10 stainless steel hand K-file to negotiate the canal to the end.
2. A 0.04 taper size 15 instrument.
3. A 0.05 taper size 20 instrument.
4. A 0.06 taper size 25 instrument.
5. A 0.06 taper size 30 instrument.
6. A 0.04 taper size 35 instrument.

Once, the instrument had negotiated to the end of the canal and had rotated freely, it was removed.

In each of these three test groups, 20 canals were enlarged. Thus, a total of 60 canals were prepared.

Evaluations

All root canal preparations were completed by one operator whilst the scanning electron microscope (SEM) evaluations and the assessment of the canal curvatures prior to and after instrumentation were carried out by a second examiner who was blind with respect to the experimental groups and who underwent a training process with reference to the scoring system of the SEM evaluations.

Table 1 Characteristics of curved root canals (n = 20 teeth per group)

	Curvature (°)			Radius (mm)		
Instrument	Mean ± SD	Min	Max	Mean ± sd	Min	Max
Mtwo	30.45 ± 3.59	25.0	35.0	6.15 ± 1.13	4.5	8.3
EasyShape	30.50 ± 3.46	25.0	35.0	6.16 ± 1.22	4.0	8.1
Coated						
Uncoated	30.50 ± 3.56	25.1	35.0	6.09 ± 1.16	4.3	8.3
P-value (ANOVA)	0.999			0.982		

Shaping ability

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 analysis of variance (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 changes of working length were analysed statistically using the 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 and statistically analysed using the Chi-square test.

Canal cleanliness

After preparation, all root canals were flushed with sodium chloride and dried with absorbent paper points. Roots were split longitudinally, prepared for SEM investigation and examined under the SEM (Philips PSEM 500X, Eindhoven, The Netherlands) at 20–2500 × magnification.

Separate evaluations were recorded for debris and smear layer. The cleanliness of each root canal was evaluated in three areas (apical, middle, and coronal third of the root) by means of a numerical evaluation scale (Hülsmann *et al.* 1997). The following scheme was used:

Debris (dentine chips, pulp remnants, and particles loosely attached to the canal wall):

- Score 1: clean canal wall, only very few debris particles.
- Score 2: few small conglomerations.
- Score 3: many conglomerations; less debris than 50% of the canal wall covered.
- Score 4: more than 50% of the canal wall covered.
- Score 5: complete or nearly complete covering of the canal wall by debris.

Scoring of debris was performed using a 200 × magnification.

Smear layer (dentine particles, remnants of vital or necrotic pulp tissue, bacterial components, and retained irrigant):

- Score 1: no smear layer, orifice of dentinal tubules patent.
- Score 2: small amount of smear layer, some open dentinal tubules.
- Score 3: homogenous smear layer along almost the entire canal wall, only very few open dentinal tubules.
- Score 4: the entire root canal wall covered with a homogenous smear layer, no open dentinal tubules.
- Score 5: a thick, homogenous smear layer covering the entire root canal wall.
- Scoring of smear layer was performed using a 100 × magnification.

The data established for scoring the debris and the smear layer were separately recorded and analysed statistically. Owing to the ordinal nature of the scores, the data were subjected to the nonparametric Kruskal–Wallis test. P values were computed and compared to the $P = 0.05$ level.

Results

During the preparation of the curved canals, one coated EasyShape instrument (0.04 taper size 15) and two uncoated EasyShape instruments (both 0.04 taper size 15, both used for the second canal) fractured. No fractures were recorded for Mtwo instruments. A total of two coated EasyShape, three uncoated EasyShape and four Mtwo files permanently deformed during preparation. The differences between the three instruments were not statistically significant in terms of the number of either fractured or permanently deformed instruments (chi-square test, $P > 0.05$).

Instrumentation results

The mean time taken to prepare the canals with the different instruments is shown in Table 2. Instrumentation with Mtwo files was significantly faster than with the two EasyShape instruments ($P < 0.05$). There was no statistically significant difference between uncoated and coated EasyShape instruments ($P > 0.05$).

All canals remained patent following instrumentation, thus, none of the canals were blocked with dentine. With all instruments, no canal had overextension of preparation. The mean changes in working length that occurred with the different instruments are listed in Table 2. The differences between the three instrument were not statistically significant ($P = 0.636$).

The mean straightening of the curved canals is shown in Table 3. The use of Mtwo files resulted in less straightening (2.41°) during instrumentation compared to both EasyShape instruments, although this difference was not statistically significant ($P > 0.05$). Little difference was obtained between coated (2.85°) and uncoated (2.80°) EasyShape instruments.

Table 2 Mean preparation time (s) and SD and mean changes in working distance (mm) and SD with the different instruments

	Preparation time (s)		Working distance (mm)	
Instrument	Mean*	SD	Mean	SD
Mtwo	182.8[a]	81.6	−0.17	0.18
EasyShape coated	263.4[b]	96.9	−0.21	0.19
EasyShape uncoated	262.8[b]	104.9	−0.17	0.21

*Values with the same superscript letters were not statistically different at $P = 0.05$.

Table 3 Mean degree of straightening of curved canals (°) and SD after canal preparation with the different instruments ($n = 20$ canals in each group)

	Straightening (°)			
Instrument	Mean	SD	Min	Max
Mtwo	2.41	2.01	0	5.1
EasyShape coated	2.85	2.65	0	7.0
EasyShape uncoated	2.80	2.54	0	8.1

Canal cleanliness

The scores for debris and smear layer are detailed in Tables 4 and 5. Completely cleaned root canals were never found (Figs 1–3). In general, the use of Mtwo instruments resulted in significantly less debris ($P < 0.05$) compared to canal preparation with both EasyShape instruments (Table 4). The use of coated EasyShape instruments resulted in significantly less debris than the use of uncoated EasyShape instruments ($P < 0.05$). The average score for debris was 2.23 for the Mtwo, 2.68 for the coated, and 3.07 for the uncoated EasyShape instruments, respectively.

In terms of smear layer (Fig. 4) no statistically significant differences were apparent when evaluating the coronal, middle and apical third separately ($P = 0.067$; $P =0.138$, and $P = 0.110$, respectively). When summarizing the results, the use of Mtwo resulted in significantly less smear layer compared to instrumentation with both EasyShape instruments ($P < 0.01$), while no significant differences were obtained between coated and uncoated EasyShape instruments ($P > 0.05$). The average score for debris was 2.95 for the Mtwo, 3.42 for the coated, and 3.61 for the uncoated EasyShape instruments, respectively.

Discussion

The aim of this study was (i) to assess both the shaping ability and the cleaning efficiency of rotary nickel–titanium Mtwo and EasyShape instruments and (ii) to evaluate the influence of the PVD-coating on the

Table 4 Summary of scores for debris

	Coronal third scores					Middle third scores					Apical third scores					Total scores				
Instrument	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Mtwo	6	10	4	0	0	4	6	10	0	0	3	6	9	2	0	13	22	23	2	0
EasyShape coated	3	6	9	1	0	2	5	10	2	0	0	2	9	5	0	5	16	28	8	0
EasyShape uncoated	3	2	10	3	0	0	3	9	6	0	0	4	6	6	2	3	9	25	15	2
P values	$P < 0.05$					$P < 0.05$					$P < 0.05$					$P < 0.001$				

Table 5 Summary of scores for smear layer

	Coronal third scores					Middle third scores					Apical third scores					Total scores				
Instrument	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Mtwo	2	7	8	3	0	1	4	9	6	0	0	3	10	6	1	3	14	27	15	1
EasyShape coated	0	2	11	6	0	0	1	10	8	0	0	2	5	9	3	0	5	26	23	3
EasyShape uncoated	0	2	11	4	1	0	0	7	9	2	0	0	7	6	5	0	2	25	19	8
P values	$P = 0.067$					$P = 0.138$					$P = 0.110$					$P < 0.01$				

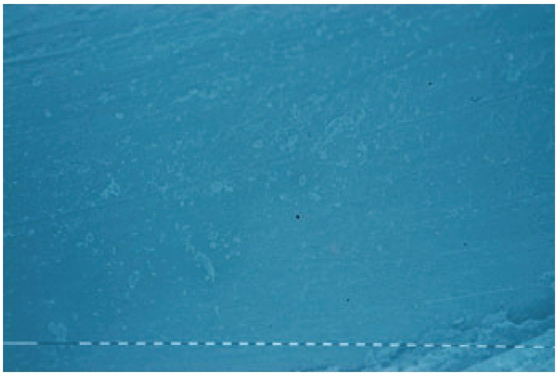

Figure 1 Canal wall after preparation with coated EasyShape files. Nearly clean canal wall with only small agglomerations of debris particles in the middle portion of the canal (score 1, magnification 160×).

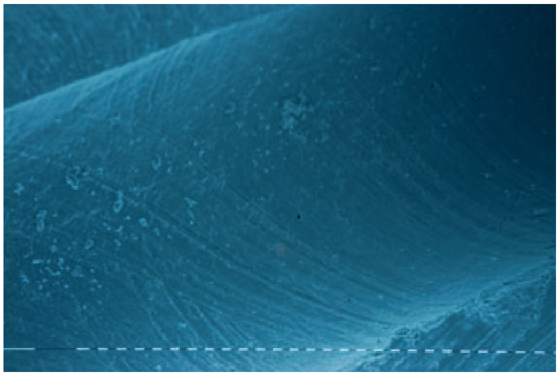

Figure 3 Canal wall after preparation with Mtwo files. Nearly clean canal wall with small agglomerations of debris particles in the apical portion of the canal (score 1, magnification 160×).

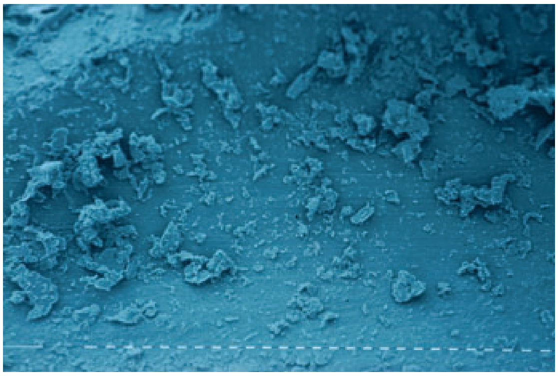

Figure 2 Canal wall after preparation with uncoated EasyShape files. Canal wall with many agglomerations of debris particles in the coronal portion of the canal (score 4, magnification 160×).

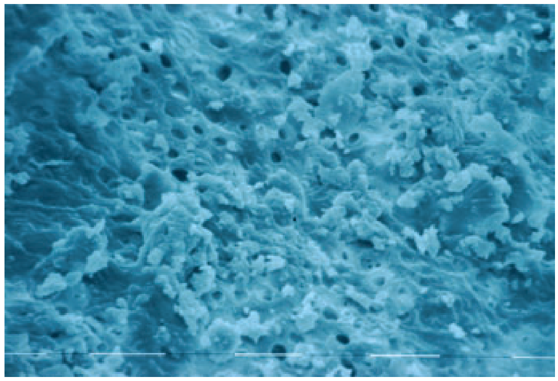

Figure 4 Canal wall after preparation with coated EasyShape files. Canal wall with homogenous smear layer along almost the entire canal wall and only few open dentinal tubules in the middle portion of the canal (score 3, magnification 600×).

shaping ability and cleaning efficiency of EasyShape instruments.

Despite the variations in the morphology of natural teeth, several attempts have been made in the present study to ensure comparability of the three experimental groups. Therefore, the teeth in all 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 analysis of variance (ANOVA) and post-hoc Student–Newman–Keuls test. According to the *P* values obtained (Table 1), the groups were well balanced. The curvatures of all root canals ranged between 25° and 35° and the radii ranged between 4.0 mm and 8.3 mm (Table 1).

In the present investigation the EasyShape files were compared with Mtwo files because both systems have an S-shaped cross sectional design with sharp cutting edges and a non-cutting tip and both instruments are used according to the single-length technique. In recently published studies, Mtwo files maintained the original canal curvatures well and displayed excellent cleaning abilities (Veltri *et al.* 2005, Schäfer *et al.* 2006).

The basic series of Mtwo instruments includes eight instruments, with tapers ranging between 0.04 and 0.07, and sizes from 10 to 40, whereas the EasyShape files range between taper 0.04 and 0.06 and sizes 15 to 40 with a stainless steel 10 K-file as the first instrument. Both manufacturers declare that a crown down instrumentation sequence is no longer required because each instrument creates a glide path to the apex for the following instrument and should be used to the full working length to shape the entire length of the canal (single-length technique).

Preparation time

Preparation time is dependent on the technique used, the operator experience and on further details of the study design (Hülsmann 2005). In the present study the preparation time included active instrumentation as well as the time required for changing instruments and irrigation in order to allow comparison of the results with those of previous studies conducted with an identical experimental setup (Schäfer & Vlassis 2004, Bürklein & Schäfer 2006, Schäfer *et al.* 2006).

Both the Mtwo and the EasyShape system consists of six instruments to prepare the root canal, but nevertheless a significant difference in the mean preparation time between Mtwo EasyShape files was observed (Table 2). It can be assumed that the main reason for this difference is the superior cutting efficiency of Mtwo instruments (Schäfer & Oitzinger 2008). Another aspect which might have influenced the different preparation times is the fact that initial instrumentation with EasyShape instruments has to be done with a stainless steel hand instrument (K-file ISO-size 10). PVD-coating exerted no significant effect on the preparation time when compared with uncoated EasyShape instruments (Table 2).

Canal straightening

The results for all instruments were comparable to those of recent investigations under identical experimental conditions (Schäfer & Vlassis 2004, Bürklein & Schäfer 2006, Schäfer *et al.* 2006). The mean straightening was 2.41° when using Mtwo and 2.80 and 2.85, respectively, when using coated and uncoated EasyShape files whereas the mean straightening for other rotary nickel–titanium instruments under identical conditions was in the range of 1.24° and 3.22° (Schäfer & Vlassis 2004, Bürklein & Schäfer 2006, Schäfer *et al.* 2006). Since the differences between coated and uncoated EasyShape instruments was not significant, PVD-coating seems to have no influence on the shaping ability of rotary nickel–titanium EasyShape files under laboratory conditions.

It can be concluded that out of all rotary nickel–titanium systems investigated under an identical experimental set-up, the instruments evaluated in this study maintained the original canal curvature well.

Instrument failure

During the present study none of the Mtwo instruments, only one coated and two uncoated EasyShape files fractured. The differences between the three instruments were not statistically significant in terms of the number of either fractured or permanently deformed instruments. Related to the total number of canals enlarged with these instruments, fracture rates of 0% (Mtwo), 5% (coated EasyShape) and 10% (uncoated EasyShape) occurred. Comparing these data with previously published studies conducted under identical experimental conditions as used in the present investigation it was found that the fracture rates were in the same range as that of other modern rotary nickel–titanium instruments (Paqué *et al.* 2005, Rangel *et al.* 2005, Yoshimine *et al.* 2005, Stewart *et al.* 2010). Thus, these files can be used to enlarge at least four canals using the instrumentation sequence described in the present study without an increased risk of instrument fracture.

Torsional fractures or cyclic flexural fatigue are possible reasons for separation of rotary nickel–titanium instruments (Sattapan *et al.* 2000) while cyclic fatigue seems to be the prime reason (Inan & Gonulol 2009). In real teeth the incidence of fracture of rotary nickel–titanium files is reported to be about 1% (Schäfer & Schlingemann 2003, Ankrum *et al.* 2004, Schäfer & Vlassis 2004, Paqué *et al.* 2005, Rangel *et al.* 2005, Yoshimine *et al.* 2005) and distortion can occur in up to 60% of the instruments used (Stewart *et al.* 2010). Nickel–titanium instruments with rectangle-based cross-sectional designs are reported to suffer from higher stress differentials during canal preparation and may encounter higher residual stress and plastic deformation than instruments with triangle-based cross sections (Kim *et al.* 2009). In contrast to this finding the cyclic fatigue resistance of Mtwo files exceeded those of instruments with a triangular cross section design (Plotino *et al.* 2010). Moreover, the metal mass influenced the fatigue resistance and greater metal mass implied a lower fatigue resistance

(Grande *et al.* 2006). Thus, as a precaution it can be recommended that the working part of rotary files should be carefully examined after clinical use and permanently deformed instruments should be discarded; instruments with a greater metal mass should be discarded sooner than small files.

Cleaning effectiveness

The removal of vital and/or necrotic pulp tissue, infected dentine, and dentine debris in order to eliminate most of the microorganisms from the root canal system is still one of the most important objectives during root canal instrumentation (European Society of Endodontology 2006). The ability to achieve some of these objectives was examined laboratory in this investigation on severely curved root canals, involving Mtwo and EasyShape rotary nickel–titanium instruments. Up to now no studies assessing the cleaning ability of the new EasyShape instruments have been published.

Debris and smear layer have been used as criteria in this study to assess the cleaning efficiency of the different instruments because debris comprises dentine chips, residual vital or necrotic pulp tissue attached to the root canal wall that is considered to be infected in many cases (Hülsmann *et al.* 1997). The smear layer is a thin surface film (1–2 μm) consisting of mainly inorganic material (American Association of Endodontists 1998) that is produced when a canal is instrumented (Grandini *et al.* 2002). Hence, no smear layer is found on areas that are not instrumented (West *et al.* 1994). Although the influence of smear layer on the outcome of the root canal treatment is controversial (Bertacci *et al.* 2007), it is recommended by several authors to remove the smear layer due to its potential deleterious effects (Lim *et al.* 2003, Serafino *et al.* 2009). This could be achieved using chelating agents (West *et al.* 1994, Hülsmann *et al.* 1997, Gambarini 1999, Grandini *et al.* 2002, Lim *et al.* 2003).

Considering the major objective of the present study (to compare the shaping and cleaning effectiveness of the different instruments) a simple irrigation protocol with only NaOCl was used, avoiding any influences of different irrigation solutions. This solution has antibacterial and organic tissue dissolving properties (Spångberg *et al.* 1973, Turkun & Çengiz 1997), but does not remove the smear layer (Yamada *et al.* 1983, Grandini *et al.* 2002, Guerisoli *et al.* 2002, Lim *et al.* 2003). Thus, it should be accentuated that the cleaning efficiency of the instruments evaluated in the present investigation might be enhanced using a combination of NaOCl and EDTA as a chelating agent.

In the present study, the cleaning efficiency was examined on the basis of a numerical evaluation scheme for debris and smear layer, by means of an SEM-evaluation of the coronal, the middle, and the apical parts of the canals (Haikel & Allemann 1988, Hülsmann *et al.* 1997). No precondition was given how to select the region of the root canal wall which was taken for scoring. It has to be taken into consideration that this election might be biased, as cleaner sections might be preferred for scoring. With all three systems, partially un-instrumented areas with remaining debris were found in all canal sections. This finding has also been described by others (Bolanos & Jensen 1980, Hülsmann *et al.* 1997, 2003, Prati *et al.* 2004, Haapasalo *et al.* 2005, Paqué *et al.* 2009, Fornari *et al.* 2010) and is consistent with other investigations using micro computer tomography assessment of canal shapes (Peters *et al.* 2001, 2003, Taşdemir *et al.* 2005, Gekelmann *et al.* 2009, Paqué *et al.* 2009). Additionally, the present results confirm previous observations that cleanliness decreased from the coronal to the apical part of the root canal (Wu & Wesselink 1995, Hülsmann *et al.* 2001, Gambarini & Laszkiewicz 2002, Hülsmann *et al.* 2003, Schäfer & Schlingemann 2003, Schäfer & Vlassis 2004, Paqué *et al.* 2005, Haapasalo *et al.* 2005, Paqué *et al.* 2009, Fornari *et al.* 2010). Therefore, sufficient disinfection and copious irrigation are essential to improve root canal cleanliness (Hülsmann *et al.* 2003, Paqué *et al.* 2005).

In general, the use of Mtwo instruments resulted in significantly less remaining debris compared to canal shaping with EasyShape instruments ($P < 0.001$), whereas for smear layer no significant differences between these instruments were obtained. A possible reason for this difference in the debris removal capacity of these instruments having similar cross sections might be the difference in their pitch design. Mtwo files possess a constantly increasing pitch length from the tip to the shaft while EasyShape instruments are characterized by a smaller pitch with progressive increasing rates over their entire working length (Fig. 5). This special design feature may enhance the debris removal capacity of Mtwo files. Certainly, further investigations should elucidate this hypothesis.

A comparison of the results obtained in previous studies under identical experimental conditions with those of the present study reveals that both Mtwo instruments and EasyShape files showed a relatively good cleaning ability. The mean score for debris was

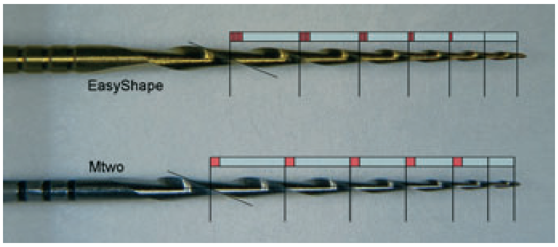

Figure 5 Comparison of the pitch length of EasyShape and Mtwo files (taper 0.04, size ISO 30). Both files show an increasing pitch length; the Easyshape file has smaller but more progressive pitches whereas the Mtwo instrument has longer and continuously increasing pitch distances.

2.23 for Mtwo, 2.68 for the coated, and 3.07 for the uncoated EasyShape instruments, respectively. In previous studies the mean scores ranged between 1.80 and 3.64 (Schäfer & Vlassis 2004, Schäfer *et al.* 2006).

In the present investigation PVD-coated EasyShape files showed significantly better results concerning the debris removal. This can be traced to the enhancement of the surface hardness which is known to result in an increased cutting efficiency (Schäfer 2002). Nevertheless, the influence of the PVD-coating on the efficiency of rotary nickel–titanium instruments is still not clear, as there are studies elucidating that other parameters seem to be more relevant (Schäfer & Oitzinger 2008, Vaudt *et al.* 2009). Further studies are necessary to analyse the influence of surface-treatment of nickel–titanium instruments by PVD-coating.

Conclusions

Within the parameters of this study both systems maintained root canal curvature well and were safe. However, the use of Mtwo files resulted in significantly lower preparation times and significantly less debris compared to canal preparation with coated and uncoated EasyShape instruments. PVD-coating of EasyShape instruments had no impact on their shaping ability but significantly improved the cleaning efficiency.

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