Root canal preparation using S5, Mtwo, and ProTaper Universal nickel-titanium systems: a comparative ex-vivo study

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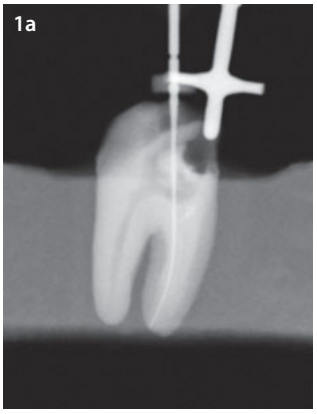
Objectives: To examine various parameters of root canal preparation using three rotary nickel-titanium systems (S5, Mtwo, and ProTaper Universal [PTU]). **Method and Materials:** One hundred and twenty curved root canals were prepared to size 30. The following parameters were evaluated: straightening, changes of root canal cross-section, safety issues, cleanliness of canal walls, and working time. Statistical analysis was performed with the Kruskal-Wallis test, Wilcoxon-Mann-Whitney test, and analysis of variance ($P < .050$). **Results:** All three systems maintained the curvature well with no significant difference between the groups. With regard to the cross-section, no significant differences for any of the root canal thirds (coronal, $P = .589$; medial, $P = .898$; apical, $P = .474$) were found. Preparation with S5 resulted in two, with Mtwo in one, and with PTU in three procedural incidents. Debris scores 1 and 2 were found in 56% (S5), 46% (Mtwo), and 60% (PTU) of the specimens, respectively. Smear layer scores 1 and 2 were found in 85% (S5), 73% (Mtwo), and 78% (PTU). Results for removal of debris and smear layer were not significantly different between the three groups. Mean working time was significantly shorter for Mtwo (293 seconds) than for S5 (329 seconds) ($P = .001$) or PTU (369 seconds) ($P = .001$). **Conclusion:** All three systems respected the original root canal curvature well and were safe to use. None of the three systems was able to prepare the entire circumference of the root canals, and to remove debris and smear layer completely. *(Quintessence Int 2019;50:358–368; doi: 10.3290/j.qi.a42326)*

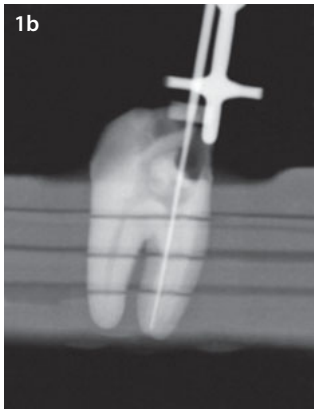
Key words: debris, nickel-titanium rotary systems, Mtwo, ProTaper Universal, S5, smear layer

For many years rotary nickel-titanium (NiTi) instruments have been proven to be excellent adjuncts for preparation of curved root canals.[1] Meanwhile, the fourth and fifth generations of instruments have been developed, for example single-file systems, single-use instruments, and instruments used in reciprocating motion.[1] Whereas many of the NiTi systems of the first generation have been investigated, and also compared to manual root canal preparation, only a few of the new systems have been investigated with reference to their benefits and limitations.[1,2] A collection of basic data concerning shaping ability, cleaning ability, and working safety should be available before recommendations for clinical use can be justified.[1] Further information on working time, as well as comparisons to other systems on the market, could assist the endodontic specialist, as well as the general dental practitioner, in their selection of a NiTi system for daily use. Only limited information is available on S5 instruments (Sendoline), which work in crown-down technique.[3] Mtwo (VDW), a single-length system, and ProTaper Universal (Dentsply Sirona), a crown-down system, have been investigated in a number of in-vitro studies.[4-14]

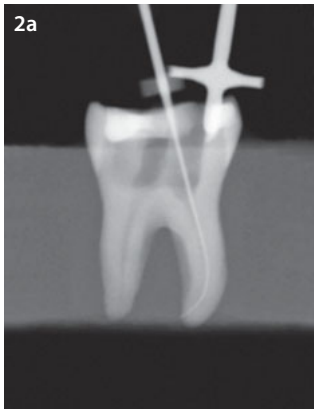
The aim of this study was to compare the clinical performance of three different rotary NiTi systems (S5, Mtwo, and ProTaper Universal) using a well-introduced study design that allows for an investigation of several properties and a comparison of these three systems to a number of different rotary NiTi systems that have been investigated using the same study design.[1,15]

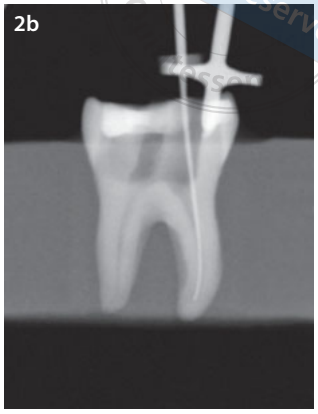
The null hypothesis (H0) was that no significant differences in root canal straightening, changes in cross-section, procedural errors, root canal cleanliness, and working time exist between S5, Mtwo, and ProTaper Universal rotary NiTi instruments.





Figs 1a and 1b Negative result of root canal straightening after preparation with S5. *(a)* Preoperative radiograph. *(b)* Postoperative radiograph after preparation of the root canal. In the upper right corner, the metallic reference object can be seen.





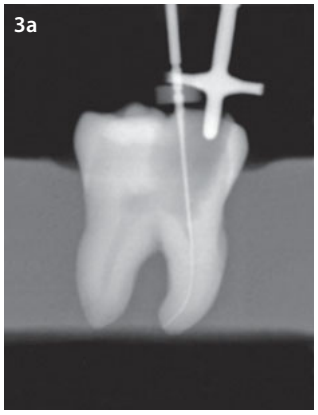
Figs 2a and 2b Negative result of root canal straightening after preparation with Mtwo. *(a)* Preoperative radiograph. *(b)* Postoperative radiograph after preparation of the root canal.

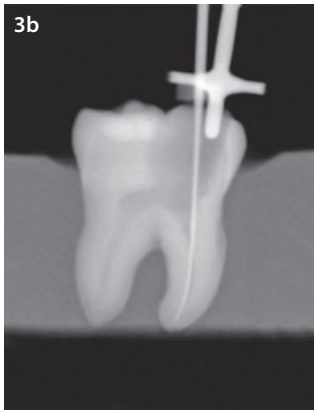
Method and materials

The study was approved by the Ethics Committee of the University (DOK_155_2016). All teeth were extracted previously for reasons not related to this study.

A modification of the Bramante technique was used to evaluate simultaneously the preparation shape (longitudinal and cross-sectional), safety issues, cleaning ability, and working time on extracted teeth under conditions comparable to the clinical situation.[16] A metal muffle-block consisting of a U-formed middle section and two lateral walls that are fixed together with three screws (University Laboratory, Göttingen, Germany) was constructed. In the present study, the same muffle-block that was used in previous studies was implemented without any modifications.[15,17-22] A modification of a radiographic platform, as described by Southard et al[23] and Sydney et al[24] could be adjusted to the outside of the middle part of the muffle. Radiographs (Trophy Elitys, Dental Imaging Company) were taken digitally at 60 kV, 4 mA, and 0.06 seconds exposure time under standardised conditions with a film holder (Dürr Dental) that was attached to the muffle-block by means of pins, assuring reproducible attachment. Two metallic reference objects, seen in Figs 1 to 3 (.10 Biostarter; Forestadent), allowed for exact superimposition of the radiographs that were taken before and after root canal preparation. The system and the evaluation technique have been previously described in detail by Hülsmann et al.[25]

Sixty extracted human mandibular molars with two separate mesial root canals were selected for this study. Inclusion criteria were as follows:





Figs 3a and 3b Negative result of root canal straightening after preparation with ProTaper Universal. *(a)* Preoperative radiograph. *(b)* Postoperative radiograph after preparation of the root canal.

- mandibular molars with clearly separate mesial and distal roots (no fusion)
- tooth length at least 19 mm (measured from occlusal edge to root tip)
- completed root development, no visible defects on the mesial root
- no previous endodontic treatment
- no visible cracks or fractures of the roots
- patency of the root canal for a size 10 instrument
- angle of curvature ranging between 20 and 40 degrees
- radius of curvature ranging between 10 and 15 mm
- no S-shaped root canals.

All preparations were performed by a final-year graduate student (FB) who had received intense supervised training in the use of all three NiTi systems. Fifteen root canals were prepared with each of the systems before the main study. Coronal access was prepared with a diamond bur (835KR.314.012, Komet) and Gates Glidden burs 2 and 3 (384843 and 384843, VDW), and mesial root canals were controlled for apical patency. A size 10 reamer (VDW) was inserted until the tip could be seen at the apical foramen and the length from the occlusal edge to the root tip was measured. The length of all teeth was reduced by shortening the tooth crown to a length of 19 mm. The working length was 1 mm shorter than the root length, therefore working length for the mesial root canals was 18 mm. The teeth were mounted into the mold with acrylic resin (Paladur, Kulzer), and isolated with rubber dam (Sigma Dental Systems), and a clamp (RDCM18, clamp number 18, Hu-Friedy), 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[26] from preoperative radiographs (Trophy Elitys) taken at 60 kV, 4 mA and 0.06 seconds exposure time, after insertion of a size 15 reamer (VDW).

Using the digital image software ImageJ (Research Services Branch; National Institute of Mental Health, Bethesda, MD, USA) the angle of the root canal curvature was determined. The radius of the root canal curvature was determined and calculated as described by Schäfer et al[27] using the same preoperative radiograph. The teeth were randomly divided into three groups, and numbered randomly (S5, n = 20; Mtwo, n = 20; ProTaper Universal, n = 20). A similar mean degree of root canal curvature and radius of curvature was achieved for all three groups by exchanging a small number of teeth (Table 1).

According to the concept of the respective NiTi system, different numbers of instruments had to be used: S5, seven instruments; Mtwo, five instruments; ProTaper Universal, seven instruments.

Root canal preparation with S5 was performed as follows: After preparation of the access cavity and scouting with a size 10 file (VDW), preparation of the root canal was performed in a crown-down technique. The instruments were operated with the S5 motor (Sendoline) as suggested by the manufacturer. The motor was adjusted to position 1 and preparation was started with S5 instrument no. 1 (size 30, taper 8%) enlarging the coronal and mesial part of the root canal. Irrigation was performed after each instrument with 2 mL of 3% sodium hypochlorite (NaOCl; lege artis). The sequence of instrumentation was as follows:

- S5, no. 1: size 30, taper 8%, coronal and middle part of the root canal
- S5, no. 2: size 30, taper 6%, coronal and middle, about 50% of working length
- S5, no. 3: size 30, taper 4%, to the apical part of the root canal
- S5, no. 4: size 25, taper 4%, to working length
- S5, no. 5: size 20, taper 4%, to working length
- S5, no. 3: size 30, taper 4%, to working length
- S5, no. 2: size 30, taper 6%, to working length.

Final irrigation was performed with 5 mL ethylenediaminetetraacetic acid (EDTA) (Calcinase, lege artis) and 5 mL NaOCl (3%). A final radiograph was taken with a size 15 instrument (VDW).

Root canal preparation with Mtwo was performed as follows: Instruments were operated with the IT Professional motor (VDW) at the constant speed and torque-control as suggested by the manufacturer. Preparation with Mtwo instruments was performed in a single-length technique in the following sequence:

- Mtwo 10/.04
- Mtwo 15/.05
- Mtwo 20/.06
- Mtwo 25/.06
- Mtwo 30/.05.

The irrigation was identical to the S5 group.

Root canal preparation with ProTaper Universal was performed as follows: Instruments were operated with the IT Professional motor (VDW) at the constant speed and torque-control as suggested by the manufacturer. Preparation with ProTaper Universal was performed in a crown-down technique in the following sequence:

- Shaping file S1: two-thirds of working length
- Shaping file SX: to resistance
- Shaping file S1: to working length
- Shaping file S2: to working length
- Finishing file F1: to working length
- Finishing file F2: to working length
- Finishing file F3: to working length (tip size 30, taper .09).

Irrigation was performed identical to the S5- and Mtwo-groups.

In all groups first the mesiobuccal root canal was instrumented in the unsectioned teeth. The mesiobuccal root canals were prepared before sectioning the teeth, because irregular hydrodynamics during irrigation of the sectioned roots could have influenced the degree of cleanliness.

Maintenance of root canal curvature, the cross-section, safety issues (loss of working length, apical blockage, instrument frac-

Table 1 Distribution of angles and radii for the three groups

System	Root canal	Mean angle of curvature (degrees)	Mean radius of curvature (mm)
S5	Mesiobuccal	28.3	13.2
	Mesiolingual	25.5	14.7
Mtwo	Mesiobuccal	26.9	12.3
	Mesiolingual	25.8	12.8
ProTaper Universal	Mesiobuccal	27.8	12.7
	Mesiolingual	25.2	13.8

Table 2 Scores for debris and smear layer (Hülsmann et al)[25]

Score	Debris	Smear layer
1	Clean root canal wall, only few small debris particles	No smear layer, dentinal tubules open
2	Few small agglomerations of debris	Small amount of smear layer, some dentinal tubules open
3	Many agglomerations of debris covering less than 50% of the root canal wall	Homogenous smear layer covering the root canal wall, only few dentinal tubules open
4	More than 50% of the root canal wall covered by debris	Complete root canal wall covered by a homogenous smear layer, no open dentinal tubules
5	Complete or nearly complete root canal wall covered by debris	Heavy, inhomogenous smear layer covering the complete root canal wall

ture, lateral perforation), cleanliness, and working time were evaluated. After preparation was finished, radiographs were taken with a stainless-steel reamer size 15 (VDW) in the root canal. With the aid of metallic reference objects (Forestadent) exact superimposition of the pre- and postoperative radiographs was performed, followed by an evaluation of the degree of straightening by measuring the angle between the two instrument tips.

Before preparation of the mesiolingual root canals the teeth were sectioned horizontally at 3, 6, and 9 mm from the apex with a micro-saw (EXAKT Apparatebau) with an uncoated 0.1-mm blade (EXAKT Apparatebau), and the preoperative root canal cross-sections of the mesiolingual root canals were photographed under standardized conditions with a microscope (Motic SMZ 168, Motic) at 40× magnification and the Lumix camera (Lumix DMC-TZ7, Panasonic). The segments were remounted into the mold and the mesiolingual root canals were prepared as described above. Again, straightening of the root canal curvature was measured using the superimposed radiographs, and at the end of preparation, the postoperative cross-sections of the mesiolingual root canal were photographed once again. According to Loushine et al[28] the postoperative cross-sections were classified as round, oval or irregular using reference photographs. Only irregular cross-sections were evaluated as unacceptable preparation results, because oval cross-sections may be a result of the cutting angle during the sectioning procedure.

The divergence of pre- and postoperative root canal cross-section was assessed by superimposing pre- and postoperative canal outlines. Divergence between pre- and postoperative cross-section was classified as follows:

- 0% contact between pre- and postoperative cross-section
- 0% to 25% contact between pre- and postoperative cross-section
- > 25% contact between pre- and postoperative cross-section
- > 50% contact between pre- and postoperative cross-section
- > 75% contact between pre- and postoperative cross-section.

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

Finally, the segments were removed from the mold and the three root segments were split longitudinally for the inspection of the root canal walls. To avoid contamination of the root canal with dentinal shavings, the cutting blade did not penetrate the complete root canal wall. The grooved segments were finally separated using a Heidemann spatula (Aesculap, Braun). The buccal half of the split root canal segments was prepared for examination with the scanning electron microscope (SEM) (DSM 960, Zeiss). The roots were coded and mixed so that the type of instrument used for preparation could not be identified during the investigation.

Separate evaluations were performed for debris and smear layer with five-score classifications for each (Tables 1 and 2). The reference photographs had previously been used in several other studies.[17–22,29,30] Debris was defined as dentin chips, pulp remnants, and particles loosely attached to the root canal wall. Scoring of debris was performed using 200× magnification and

smear layer at 1,000× magnification. The scoring technique and the scores used have previously been described in detail.[25] Smear layer was defined as proposed by the American Association of Endodontists' Glossary of Endodontic Terms as a surface film of debris retained on dentin or other surfaces after instrumentation with either rotary instruments or endodontic files; consisting of dentin particles, remnants of vital or necrotic pulp tissue, bacterial components, and retained irrigant.[31]

The central beam of the SEM was directed to the center of the object by the SEM operator under 10× magnification. Following this the magnification was increased to 200× and 1,000×, respectively, and the canal wall region that appeared on the screen was scored. The scoring procedure was performed by a blinded second operator (MH), who had not prepared the root canals and could not identify the coded specimens or the device used for root canal preparation. This operator had been trained in the scoring procedure intensively, resulting in a sufficient intraobserver reproducibility (Cohen's Kappa > 0.800).

Preparation time, without time for irrigation and instrument change, was protocolled.

Statistical analysis

Statistical analysis was performed with SPSS 17 software (IBM) using the Kruskal-Wallis test for straightening, comparison of the cross-sections and root canal cleanliness; analysis of working time was performed using the Kruskal-Wallis test and the Wilcoxon-Mann-Whitney test. For all tests the level of significance was set at $P < .050$.

Results

Straightening

The mean degree of straightening after preparation was 1.1 degrees (mesiobuccal) and 1.0 degrees (mesiolingual) in the S5 group, 0.9 and 0.7 degrees, respectively, in the Mtwo group, and 1.4 and 1.3 degrees, respectively, in the ProTaper Universal group. The maximum degree of straightening was 5.9 degrees for S5, 5.8 degrees for Mtwo, and 7.7 degrees for ProTaper Universal.

In all groups more than 50% of the root canals showed less than 1 degree of straightening. The statistical analysis did not show any significant differences between the groups (Kruskal-Wallis test: $P = .510$ mesiobuccal and $P = .433$ mesiolingual). As it pertains to the radius of the curvature, the results were similar. Mean changes in radius were 0.7 mm (mesiobuccal) and 1.1 mm (mesiolingual) for S5, 0.5 mm (mesiobuccal) and 0.8 mm (mesiolingual) for Mtwo, and 0.9 mm (mesiobuccal) and 0.8 mm (mesiolingual) for ProTaper Universal, with no significant differences between the groups (Kruskal-Wallis test: $P = .418$ mesiobuccal and $P = .500$ mesiolingual).

Negative examples for root canal straightening after preparation are shown in Figs 1 to 3.

Cross-sections

In the coronal part of the root canals S5 showed irregular cross-sections in five specimens, and Mtwo and ProTaper Universal both in four of 20 specimens. In the middle sections of the root canals S5 and ProTaper Universal both showed five specimens with irregular cross-sections, and Mtwo showed six. In the apical sections S5 showed eight specimens with irregular cross-sections, Mtwo 2 and ProTaper Universal showed three. Statistical analysis using the Kruskal-Wallis test did not show significant differences between the groups for any of the three parts of the root canal (coronal, $P = .956$; medial, $P = .834$; apical, $P = .074$) (Table 3).

Superimposition of photographs of the pre- and postinstrumentation cross-sectional form of the root canals showed that all systems left uninstrumented canal walls (Table 4). Statistical evaluation revealed no significant differences between the three systems for any of the root canal thirds (coronal, $P = .589$; medial, $P = .898$; apical, $P = .474$).

Procedural errors

In 111 root canals, preparation could be finished without procedural errors such as perforations, ledging, instrument fracture, apical blockage, or loss of working length. However, four specimens were lost during the study due to procedural problems. For S5 two cases of ledging were noted. One instrument size 10/.04 fractured in the Mtwo group in a root canal with a 20.7-degree curvature. Preparation with ProTaper Universal resulted in one apical blockage as well as in two cases with loss of working length. The total number of incidents was six in 117 root canals (5.1%). Statistical analysis using the Kruskal-Wallis tests did not show any difference between the systems (mesiobuccal $P = .131$, mesiolingual $P = .299$).

Root canal cleanliness

The results of the SEM analysis of the root canal walls, concerning residual debris and smear layer, are summarized in Table 5. Gen-

Table 3 Distribution of cross-sections (number of specimens)

Root canal segment	Cross-section	S5		Mtwo		ProTaper U	
		Total	Acceptable	Total	Acceptable	Total	Acceptable
Coronal	Round	13	14	10	14	10	15
	Oval	1		4		5	
	Irregular	5		4		4	
Medial	Round	9	14	7	12	10	14
	Oval	5		5		4	
	Irregular	5		6		5	
Apical	Round	6	11	8	16	9	16
	Oval	5		8		7	
	Irregular	8		2		3	
Total*		57	39	54	42	57	45

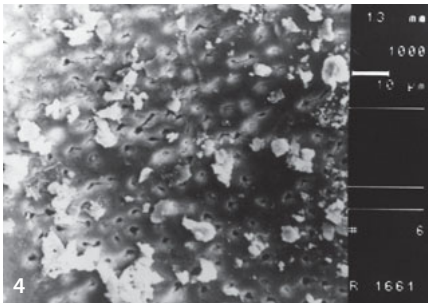
*Due to loss of some specimens the total number of observations is less than 60 in all groups.

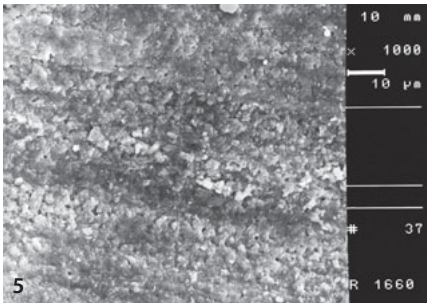
Table 4 Contact between pre- and postoperative cross-section

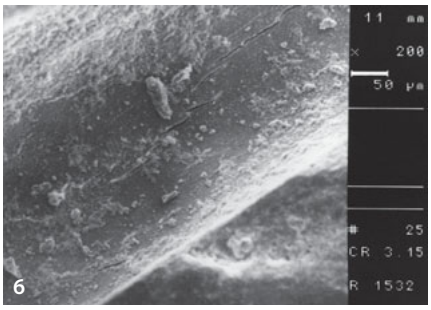
System	Segment	Contact between pre- and postoperative cross-section				
		0%	> 0% to ≤ 25%	> 25%	> 50%	> 75%
S5	Coronal	11	6	2	0	0
	Medial	9	7	2	1	0
	Apical	8	5	2	4	0
Mtwo	Coronal	11	5	0	2	0
	Medial	8	8	1	1	0
	Apical	4	5	6	3	0
ProTaper Universal	Coronal	12	3	3	1	0
	Medial	9	7	2	1	0
	Apical	6	4	4	5	0

Table 5 Distribution of the scores of the SEM investigation for smear layer

System	Score	Segment			Total
		Coronal	Medial	Apical	
S5 (n = 60)	1	15	15	6	36
	2	3	4	8	15
	3	1	1	2	4
	4	1	0	3	4
	5	0	0	1	1
Mtwo (n = 60)	1	14	13	10	37
	2	3	3	1	7
	3	2	2	2	6
	4	1	1	5	7
	5	0	1	2	3
ProTaper Universal (n = 60)	1	15	14	4	33
	2	3	5	6	14
	3	2	1	6	9
	4	0	0	3	3
	5	0	0	1	1







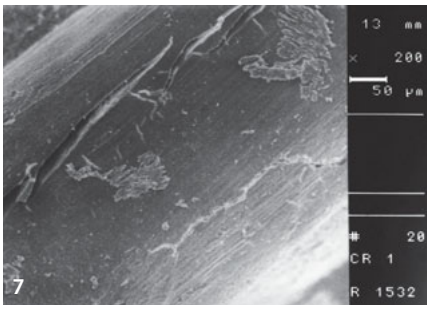


Fig 4 Smear layer score 2: Small amount of smear layer, some dentinal tubules are open. The scores were previously described by Hülsmann et al.[25]

Fig 5 Smear layer score 3: Homogenous smear layer covering the root canal wall, only few dentinal tubules open.

Fig 6 Debris score 2: Few small agglomerations of debris.

Fig 7 Debris score 3: Many agglomerations of debris covering less than 50% of the root canal wall.

erally, the root canals showed only small amounts of remaining debris which in turn results in a high number of scores 1 and 2 for all systems (Table 5). Figures 4 and 5 show smear layer scores 2 and 3. Figures 6 and 7 show debris scores 2 and 3, respectively.[25]

Smear layer

For S5, 85% of the specimens were scored as acceptable (scores 1 or 2), for Mtwo 73%, and 78% for ProTaper Universal, respectively. The best results were found in the middle segments of the S5 and the ProTaper Universal groups, with 95% acceptable specimens. The number of specimens with score 1 was similar for all three groups (S5, 36; Mtwo, 37; ProTaper Universal, 33). Statistical analysis, using the Kruskal-Wallis test, did not reveal any significant differences between the three groups for any of the root canal thirds (coronal $P = .906$, medial $P = .628$, apical $P = .733$) (Table 5).

Debris

For S5 and ProTaper Universal the majority of specimens were rated with the scores 1 or 2, indicating acceptable cleanliness (S5, 56%; ProTaper Universal, 60%), whereas for Mtwo only 46% were scored as acceptable. The results for the coronal and medial segments were superior to those for the apical part of the root canal. Statistical analysis using the Kruskal-Wallis test did not indicate any significant differences between the groups (coronal $P = .157$, medial $P = .266$, apical $P = .348$) (Table 6).

Working time

Working time was measured only for preparation. No significant differences were found for preparation of the mesiolingual root canals ($P = .499$). For the mesiobuccal root canal a significant difference was detected ($P = .001$). The Wilcoxon-Mann-Whitney test showed significant differences between all groups (S5 vs Mtwo, $P = .001$; S5 vs ProTaper Universal, $P = .047$; Mtwo vs ProTaper Universal, $P = .001$).

Discussion

No significant differences in root canal straightening, changes in cross-section, root canal cleanliness, and procedural errors were detected between the three NiTi systems investigated in this study. Therefore, the null hypothesis (H0) could not be rejected for these parameters. For working time significant differences were found, therefore the null hypothesis (H0) could be rejected for this parameter.

To respect the original anatomy of the root canal can be challenging in curved root canals. Flexible NiTi instruments have clearly facilitated preparation of such curved root canals. Previous studies, using the same methodology as the present investigation, came to the conclusion that NiTi systems constantly and reproducibly achieve better results for preparation of curved root canals than stainless steel instruments.[17-22] Recent studies on root canal preparation with rotary NiTi instruments

preferably are performed using micro-computed tomography (micro-CT), which represents a precise and noninvasive method to evaluate geometric differences between pre- and postoperative root canal morphology three-dimensionally.[32,33] This study used the same technique as previous studies, in order to allow comparison between the different NiTi systems.[17-22] Unfortunately, the micro-CT technique is not able to score root canal cleanliness in terms of debris and smear layer, which is only possible under the SEM after sectioning of the roots. Therefore, to allow comparison with the results of earlier studies, a well-established methodology was used in the present study.[17-22]

The mesiobuccal root canal was prepared in unsectioned roots in order to avoid irregular hydrodynamics during irrigation, which could influence cleanliness. Then the root canal cross-section was photographed in the mesiolingual root canal after horizontal sectioning of the tooth was completed, and the second root canal was prepared accordingly after reassembling the sections in the muffle system. Superimposition of the photographs of the pre- and postoperative cross-sections allowed for evaluation of changes in the transversal plane of the root canal.

The present study design only allowed the operator to take radiographs from the buccal side of the tooth. Vaudt et al[34] described a method that allows taking radiographs also from the mesial angle. This modification of the method allows for investigation of root canal straightening from two different angles and provides more information.

Some concern may arise as all preparations were performed by a final-year graduate dental student. The student was trained before the study took place under the supervision of an experienced endodontist (MH). During the supervised training the student prepared 15 root canals with each of the three systems. It has been demonstrated, in a number of studies, that the operator's influence on the quality of shaping, and on the incidences of instrument fractures, is negligible or low when using rotary NiTi instruments.[35-38] In some studies, working time was adversely related to the experience of the operator.[35,39]

In the present comparative ex-vivo study, the shaping and cleaning ability of three different NiTi systems was investigated; among these was S5, which has been investigated in only one study so far.[13] The results do not show any significant differences between the three examined systems. In all groups root canal curvature could be maintained well, and in the majority of root canals straightening was less than 1 degree, which is supported by comparable studies from the recent literature.[40-42]

One study compared Mtwo and ProTaper with Reciproc (VDW) and WaveOne (Dentsply Sirona) instruments. No instrument fractured, and also there was no statistical difference between all instruments regarding the maintenance of the original root canal curvature.[43]

Table 6 Distribution of the scores of the SEM investigation for debris

System	Score	Segment			Total
		Coronal	Medial	Apical	
S5 (n = 60)	1	9	5	4	18
	2	5	6	5	16
	3	6	8	7	21
	4	0	1	3	4
	5	0	0	1	1
Mtwo (n = 60)	1	9	11	3	23
	2	3	1	1	5
	3	6	6	6	18
	4	2	1	8	11
	5	0	1	2	3
ProTaper Universal (n = 60)	1	15	12	4	31
	2	1	3	1	5
	3	3	2	10	15
	4	1	3	5	9
	5	0	0	0	0

One of the main differences between the three systems investigated relates to the geometry of the file tip: all instrument tips used for final preparation show a size 30, but tapers differ from 5% (Mtwo), approximately 6% (S5), to 9% (ProTaper Universal). These differences in apical taper and resulting apical flexibility of the files obviously do not negatively affect shaping ability in moderately curved molar root canals.

Regarding the cross-section, the root canal preparation ideally should touch the entire circumference of the root canal and prepare a round cross-section. It has repeatedly been demonstrated that this aim is difficult to achieve with any preparation technique or instrument. Nevertheless, all three systems investigated in this study showed satisfactory results in the majority of cases without any significant differences between the file systems.

When a root canal is prepared in its entire circumference, no contact between pre- and postoperative cross-section should be found (0%). This was achieved in 28 specimens of the S5 group, in 23 specimens of the Mtwo group, and in 27 specimens of the ProTaper Universal group, but the differences between the systems once more were not significant. In another study, Mtwo (30.05) and ProTaper Universal (F3) were compared using a micro-CT. Approximately 39% to 42% of the root canal walls remained unprepared, which is clearly inferior to the results of the present study.[7]

These unsatisfactory findings at least partially will be due to the diameter and the taper of the instruments. A final prepara-

tion size 30 seems to be too small to reach the complete circumference of the root canal in moderately curved root canals; on the other hand, larger sizes might be inappropriate in more severely curved or in oval root canals, resulting in straightening or strip perforations. Final preparation size should be determined individually with respect to shape and curvature of the root canals with regard to the limitations of the respective instrument size.

There were only a few procedural incidents for the three systems, with only one instrument fracture after preparation of 120 curved root canals. All tested NiTi systems can be regarded as safe to use. Also, other studies using this method and different NiTi instrument systems showed that fractures rarely occur. A study examined Mtwo, ProTaper, WaveOne, and Reciproc files with no instrument fractures.[43] Another study investigated Mtwo, Reciproc, F360 (Komet), and OneShape (Micro-Mega) with no fractures during preparation of severely curved root canals.[44]

Evaluation of root canal wall cleanliness was performed only in the mesiobuccal root canals, which were prepared before sectioning of the roots. Therefore, the small substance loss during horizontal sectioning could not influence irrigation hydrodynamics. The SEM investigation showed acceptable cleanliness for all three systems with regard to debris and smear layer. Nevertheless, complete clean root canal walls without debris and smear layer could not be achieved with any of the systems, which underlines the need for thorough activated irrigation. Another study examined the cleanliness of ProTaper, Mtwo, and K3 (Kerr) and found no significant difference between these systems ($P = .237$). Also, in this study the apical third was significantly less clean than the other root canal areas.[45]

One reason for the slight differences in working time for the three systems is due to the differing number of instruments used for preparation. A large difference in the clinical situation is not to be expected when adding the time for irrigation, although working time was significantly different in some of the examined systems. The faster working time for Mtwo can be explained by the more aggressive cutting design of the files (Hedstroem-file with two flutes). Furthermore, time needed for preparation of a root canal is not only related to the instruments used, but also to an unknown and differing degree to the operator's working speed and power of use.

In summary, root canal preparation with NiTi instruments seems to be safe. Nevertheless, instrument fractures occur depending on the taper, cross-section, and the anatomy of the root canal. It is highly recommended to keep to the manufacturers' recommendations concerning speed, torque and frequency of use, and also to carefully inspect the instruments after usage for fractures and deformations.[46,47]

A number of studies have used the same study design to compare different NiTi systems for root canal preparation. The systems Quantec SC (Sybron Endo), FlexMaster (VDW), HERO 642 (Micro-Mega), GT Rotary, ProFile 04 and ProTaper (all Dentsply Sirona), RaCe (FKG), NiTi-Tee (Loser), LightSpeed, and K3 (both Kerr) have been compared.[17-21,29,48-50] Root canals in these studies were prepared to size 45 or to the largest available instrument. Using the same method for all of these different NiTi instrument systems allows for comparison of the examined parameters (root straightening, root cross-section, safety, cleaning efficacy, and working time), although preparations in those studies were performed by different operators. There was no significant difference in root canal straightening between the different NiTi systems. Only Quantec SC showed significant straightening, which could be due to the actively cutting tip. The examination of the cross-sections showed that with all instruments there remained a large amount of unprepared root canal wall. The round shape of NiTi instruments and their flexibility prevent the file from touching all areas of the root canal walls.[48] The safety of all systems was relatively good and only a small number of instrument fractures occurred in most of the investigated systems. This could be due to the limited experience of the operators, although previous training had been performed in all studies. Working time was shorter than needed for manual preparation but showed a large variance between the systems due to different numbers of files needed. Also, the comparison of cleanliness showed that no instrument system was able to completely remove debris and smear layer from the root canal walls. Debris removal was generally more effective than smear layer removal and the cleanliness decreased from coronal to apical for all systems. Regarding working time, the experience of the operator has some influence on this issue. Working time has been demonstrated to decrease with increasing experience.[35,39] The comparison of various parameters of root canal preparation for the three NiTi systems S5, Mtwo, and ProTaper Universal demonstrated significant differences only for the working time. For the more important aspects 'straightening', 'alteration of radius', 'cross-section', 'difference between pre- and postoperative cross-section', 'working safety', and 'canal wall cleanliness', no differences were detected, indicating that all three systems are equally suited for preparation of moderately curved root canals.

All three NiTi systems can be recommended for preparation of curved root canals. Addition of files with larger apical size is recommended to reduce the frequency and amount of uninstrumented areas namely in the apical part of the root canals.

Conclusions

The present study, with a final apical size 30 for moderately curved root canals in mandibular molars, demonstrates that this instrument size may be considered as insufficient to achieve an ideal cross-sectional shape. The results for cleanliness emphasize the need for thorough (activated) irrigation.

All instruments respected original root canal curvature well, were safe to use, and can be recommended for clinical use.

Declaration

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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