Root canal shaping with manual stainless steel files and rotary Ni–Ti files performed by students

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Abstract

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Aim To investigate root canal shaping with manual stainless steel files and rotary Ni–Ti files by students.

Methodology Two hundred and ten simulated root canals with the same geometrical shape and size in acrylic resin blocks were prepared by 21 undergraduate dental students with manual stainless steel files using a stepback technique or with rotary Ni–Ti files in crown-down technique. Preparation length, canal shape, incidence of fracture and preparation time were investigated.

Results Zips and elbows occurred significantly ($P < 0.001$) less frequently with rotary than with manual preparation. The correct preparation length was achieved significantly ($P < 0.05$) more often with rotary Ni–Ti files than with manual stainless steel files. Fractures occurred significantly ($P < 0.05$) less frequently with hand instrumentation. The mean time required for manual preparation was significantly ($P < 0.001$) longer than that required for rotary preparation. Prior experience with a hand preparation technique was not reflected in an improved quality of the subsequent engine-driven preparation.

Conclusions Inexperienced operators achieved better canal preparations with rotary Ni–Ti instruments than with manual stainless steel files. However, rotary preparation was associated with significantly more fractures.

Keywords: dental education, nickel–titanium, root canal preparation, simulated root canals, teaching, undergraduate.

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Introduction

Many studies have demonstrated that the quality of root canal treatment by dental practitioners in Europe is poor (Saunders *et al*. 1997, Weiger *et al*. 1997, Marques *et al*. 1998). The European Society of Endodontology have issued guidelines pointing out that it is important to bring undergraduate training in endodontics to a level 'that ensures that standards in clinical practice improve' (ESE 2001).

The current standard practice in Europe is still hand preparation with stainless steel files (Qualtrough *et al*. 1999). Moreover manual techniques are taught at most universities. However, the success and safety of hand preparation with stainless steel files are dependent upon experience and practice.

With the objective of improved endodontic training, various models of a modified teaching course have been investigated and discussed (Fouad & Burleson 1997, Plasschaert *et al*. 1997). For example, the introduction of highly flexible Ni–Ti files has expanded the therapeutic options available for root canal preparation.

Numerous authors have reported mechanical advantages of preparation with Ni–Ti files over preparation with stainless steel files (Esposito & Cunningham 1995, Gambill *et al*. 1996, Garip & Gunday 2001).

Various studies have been carried out on preparation with Ni–Ti files in undergraduate training. Pettiette *et al*. (1999, 2001) examined the use of Ni–Ti hand files and concluded that the results of their studies justify their use. Other investigators turned their attention to

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preparation with rotary instruments and reported that the advantages of this method of preparing curved canals could be exploited not only by experienced dentists but also by less experienced operators (Baumann & Roth 1999, Namazikhah *et al.* 2000, Gluskin *et al.* 2001). However, practice and experience are indispensible for safe application of this technique (Mandel *et al.* 1999).

The primary risk inherent in shaping with rotary Ni–Ti files is the susceptibility of the instruments to fracture, a problem that has been addressed in numerous reports (Pruett *et al.* 1997, Turpin *et al.* 2000).

The extent to which the use of rotary Ni–Ti files in undergraduate training enhances the quality of preparation has not yet been adequately investigated. One crucial issue is to evaluate the risk of fracture during mechanical preparation, against the risk of canal transportation and the creation of aberrations with hand preparation.

The aim of the present study was to evaluate: (i) whether mechanical root canal preparation with rotary Ni–Ti files enables inexperienced operators to achieve better maintenance of the original canal shape than hand preparation with stainless steel K-files and (ii) whether practising a hand preparation technique prior to performing rotary canal preparation results in an improved quality of the rotary canal preparation.

Materials and methods

Twenty-one undergraduate students at the dental school of the Philipps University, Marburg, Germany with no practical experience in root canal preparation were asked to prepare 210 severely curved simulated root canals in plastic specimens (VDW, Munich, Germany). The canals had a length of 19 mm, a curvature radius of 5.5 mm, and an angle of 40° measured according to Schneider (1971).

Specimens and instruments

A serial number from 1 to 210 was engraved in the acrylic blocks containing the simulated root canals (SRC) with a small diamond bur (Komet, Lemgo, Germany). Small crosses were engraved to the right and left of the canal entrance to ensure accuracy in subsequent superimpositioning of the images. A 0.1% aqueous methylene blue solution (pharmacy of Philipps University) was injected into the canals to enhance the image contrast and to verify that the canals were suitable for instrumentation. If the solution failed to emerge through the apical foramen (AF), the block was discarded and replaced with a new one. The blocks were photographed in a purpose-designed stand (Precision Mechanics Workshop, Philipps University, Marburg, Germany) in a reproducible position with a digital camera (Camedia C2500L, Olympus, Tokyo, Japan) and the image data stored in a PC (Compaq Computer Corp., Houston, USA). The methylene blue solution was then flushed out of the canals with water to prevent any obliterations due to drying of the dye.

The numbered blocks were randomized using software that can be accessed through the Internet (http://www.random.org). The column of numbers generated in this way was divided in ascending order into 21 groups with 10 numbers each, with each group being allocated to one of the 21 students taking part in the study. In addition, the numerical sequence produced by the random generator was used to determine the sequence in which the individual SRC were to be prepared. The resulting allocations were entered in a coding list from which the respective student, the preparation system, and the serial number could be drawn for each SRC.

The students were also allocated a number put into random sequence by means of the software specified above. The persons coded with the first 11 numbers were assigned to operator group A, and the others to group B. The coding lists in which the randomized assignment was recorded were kept by the study director.

Group A started with the manual, and group B with the rotary preparation (Table 1). In addition to the lectures on endodontics, a 2-h lecture on the respective preparation techniques and the instruments to be used was held for both groups before the start of the trial. This was followed by preliminary practice in the form of preparing a SRC up to size 35 with a .02 taper preparation. These preparations were not taken into account in the study. On completion of the preliminary practice, the

Table 1 Working sequence in groups A and B

	Group A (11 persons)	Group B (10 persons)
1	Lecture and hand preparation of one SRC as a preliminary exercise	Lecture and rotary preparation of one SRC as a preliminary exercise
2	Hand preparation of five SRCs	Rotary preparation of five SRCs
3	Lecture and rotary preparation of one SRC as a preliminary exercise	Lecture and hand preparation of one SRC as a preliminary exercise
4	Rotary preparation of five SRCs	Hand preparation of five SRCs

SRC, simulated root canal.

Table 2 Instruments and working sequence in manual shaping technique

	Instrument	Sequence
Preflare	Gates-Glidden drills	Sizes: 110, 90, 70
Full working length (18 mm)	Stainless steel Flexicut® files	Sizes: 15, 20, 25, 30, 35, all .02 taper
Stepback (17 mm)	Stainless steel Flexicut® file	Size: 40, .02 taper

student was given his/her first coded block in accordance with the above allocation. When a completely prepared SRC had been returned, a new block was issued to the student by the study director.

Root-canal preparation

In both groups, preflaring was performed with Gates-Glidden drills (Komet, Lemgo, Germany) in a crown-down technique no further than the start of the middle third of the canal (Tables 2 and 3). After each change of instrument, the root canals were irrigated with 1 mL water to remove debris.

The working length of the canals was set at 18 mm, corresponding to a distance of 1 mm from the apical foramen. The working length of each instrument was set by the students themselves with rubber stoppers prior to the start of treatment and was checked in the course of treatment. Using a new set of instruments, five canals were prepared by each student without the instruments being replaced.

Hand preparation was performed with 25-mm-long .02 taper Flexicut® stainless steel (SS) files (VDW). For optimized canal preparation, the instruments were prebent by the students and applied in a linear filing motion using the stepback technique (Table 2). Between each change of instruments the canals were irrigated with 1.5 mL water. If necessary, the canals were recapitulated with a previously used smaller file.

Rotary preparation was performed with 25-mm-long FlexMaster® Ni–Ti rotary files (VDW, Munich, Germany) driven at 250 r.p.m. by an Endostepper® torque-controlled low-speed motor (VDW) adapted to the individual instruments using a modified crown-down technique (Table 3). Shaping was done with a gentle advance and withdrawal. Before an instrument was inserted into the canal, it was coated with Glyde® (Dentsply De Trey, Konstanz, Germany), and the canals were irrigated with 1 mL water between each change of instruments. On completion of the canal preparation, a gutta-percha cone size 35/.02 taper (VDW) was cut off at working length and inserted without sealer into the canal as far as the apical stop.

All prepared root canals were once again photographed with a digital camera in standardized position and the images stored in a PC. In contrast to the first photo, however, the canals were not filled with dye and the blocks were placed against a black background. After preparation of all blocks, a multiple-choice questionnaire for subjective assessment of the hand and rotary root canal preparation was issued to the students. The completed questionnaires were returned anonymously.

Measurement techniques

All prepared canals were pooled and evaluated by a member of staff who had no access to the coding lists and who was unaware of the instrumentation technique used to prepare the canal. Aberrations of the prepared canals were assessed under 32× magnification on a 17′ monitor (Belinea, Maxdata, Marl, Germany) using Adobe Photoshop® 5.5 software (Adobe, Mountain View, USA). Assessments were made according to the presence and position of various types of canal aberrations, such as apical zip (Fig. 1), elbow (Fig. 2) and ledge (Fig. 3).

The preparation length was assessed under 20× magnification under a light microscope (Zeiss, Oberkochen, Germany) with reference to the master points (MP) located in the canals in relation to the apical foramen. A division was undertaken into three categories: (i) MP ending 0–2 mm from the apical foramen; (ii) MP ending ≥2 mm from the apical foramen; and (iii) MP pushed beyond the apical foramen.

The apical foramen was assessed by light microscopy under 40× magnification. Three groups were used for classification purposes: (i) intact apical foramen; (ii) instrumented apical foramen; and (iii) blocked apical foramen.

Table 3 Instruments and working sequence in rotary shaping technique

	Instrument	Sequence
Preflare	Gates-Glidden drills	Sizes: 110, 90, 70
Crown-down (to working length)	FlexMaster® Ni–Ti files	Sizes: 30/.06 taper, 25/.06, 20/.06, 30/.04, 25/.04, 20/.04
Apical preparation (18 mm)	FlexMaster® Ni–Ti files	Sizes: 20/.02 taper, 25/.02, 30/.02, 35/.02, 25.04, 30/.04

Figure 1 Funnel canal shape in the apical third of a prepared root canal.

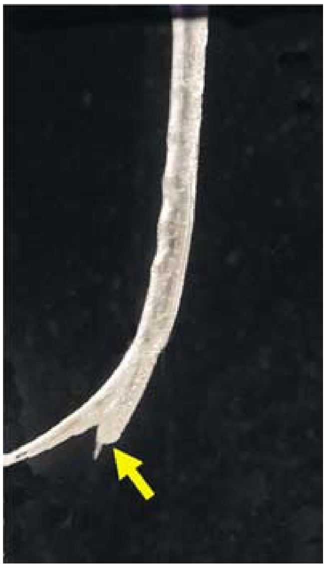

Figure 3 Deviation from the outer canal curvature resulting in the formation of a 'ledge'.

Transportation of the canal was measured at points 1, 3, 5, 7, 9 and 11 mm from the apical foramen (Fig. 4). For these measurements, the images were calibrated in Photoshop® 5.5 software before and after root canal preparation and superimposed by means of the engraved reference points. The canal transportation was determined under 32× magnification by the method described by Luiten *et al.* (1995). The increase in canal width due to the instrumentation process was determined on the inner and outer sides of the canal, starting from the original canal. These measurements were designated as the inner and outer post-instrumentation widths.

Figure 2 Hour-glass canal shape in the apical third of a prepared root canal.

Canals were considered to be transported at the measuring points if the increased width of either the inner or outer post-instrumented canal exceeded the post-instrumentation width of the opposite side by a factor of 3. This factor was calculated mathematically after entry of all data, using Excel®, and Office 2000 software (Microsoft, Redmond, USA).

If an instrument failed during canal preparation, the ISO size and taper as well as the number of the SRC being prepared, were noted. The fractured instrument was replaced with a new file and the next SRC was issued to the student. The prepared canal was not included in the further evaluation of the investigated parameters.

The preparation time required for the canal was recorded in minutes by each student. The time after use of the Gates-Glidden drills until insertion of the masterpoint was measured. The recorded time covered irrigation, instrument changes and recapitulations.

Statistical analysis

Statistical analysis of the collected data was performed with SPSS® 10.0 statistics software (SPSS, Inc., Chicago, USA). Statistical analysis covered: (i) manual versus

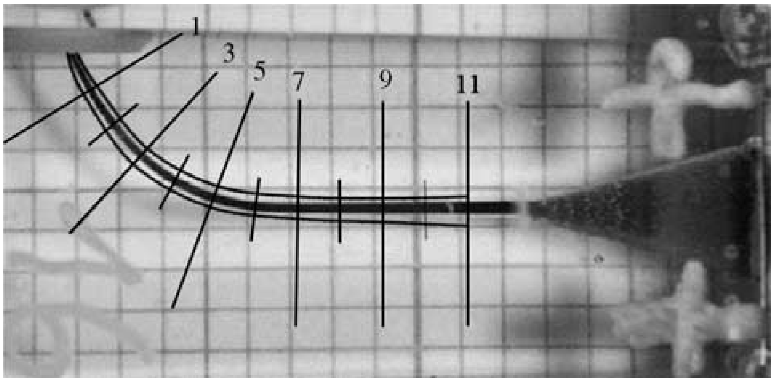

Figure 4 Photo of the untreated canal with a tracing of the mean amount of material removed by rotary preparation. The figures denote the distance of the measuring points from the apical foramen (AF).

mechanical preparation (groups A and B combined) and (ii) rotary preparation results of group A versus those of group B.

The measured data of the interval-scaled values (canal transportation and preparation time) were first checked for normal distribution with the Kolmogorov–Smirnov test. In the absence of normal distribution, further analysis was performed with nonparametric Mann–Whitney *U*-tests. In the presence of normal distribution, the parametric *t*-test for comparison of two independent samples was used.

The chi-square test was used for evaluation of nominally or ordinally scaled values (preparation length, AF, canal aberrations). If a significant difference was registered with the chi-square test, the individual values were specified by means of standardized residues. Differences revealed in the data were designated as significant at $P < 0.05$.

Results

Manual versus mechanical preparation

The data were first examined with reference to the first hypothesis, aimed at clarifying whether rotary root canal preparation with Ni–Ti (FlexMaster®) files allows inexperienced operators to maintain the original canal shape better than manual preparation with stainless steel (Flexicut®) files.

Aberrations

The proportion of zips resulting from hand preparation was significantly ($P < 0.001$) above that resulting from rotary preparation. The number of elbows produced in hand preparation was significantly ($P < 0.001$) higher than that for rotary preparation. The quantity of recorded ledges did not differ significantly between the two techniques (Table 4).

Preparation lengths

With hand preparation, significantly fewer of the inserted master points (MP) attained the correct preparation length compared with rotary file preparation. The proportion of MP > 2 mm from the apical foramen was 53.3% with manual versus 3.8% with mechanical preparation. The proportion of MP extending beyond the apical foramen with manual preparation did not differ significantly from the results recorded in the group of mechanically shaped canals (Table 5).

Assessment of the apical foramen

An intact, nonblocked apical foramen was found significantly ($P < 0.01$) less often after manual than after mechanical preparation. In 34.3% of all manually prepared canals, the apical foramen showed traces of instrumentation. The difference from the values recorded for mechanical preparation was not significant. Debris-blocked apical foramens were recorded significantly

Table 4 Frequency of morphological canal aberrations (zip, elbow, ledge) with manual and rotary preparation

Aberration type	Manual (SS) (%)	Rotary (Ni–Ti) (%)	*P*-values
Zip	49.5	9.5	<0.001
Elbow	65.7	17.1	<0.001
Ledge	6.7	1.9	NS

Table 5 Assessment of the preparation length with masterpoints (MP) positioned in the canal (AF, apical foramen)

Distance of MP from AF	Manual (SS) (%)	Rotary (Ni–Ti) (%)	*P*-values
MP: 0–2 mm	43.8	79.8	<0.05
MP: >2 mm	53.3	3.8	<0.001
MP: <0 mm	1.0	2.9	NS

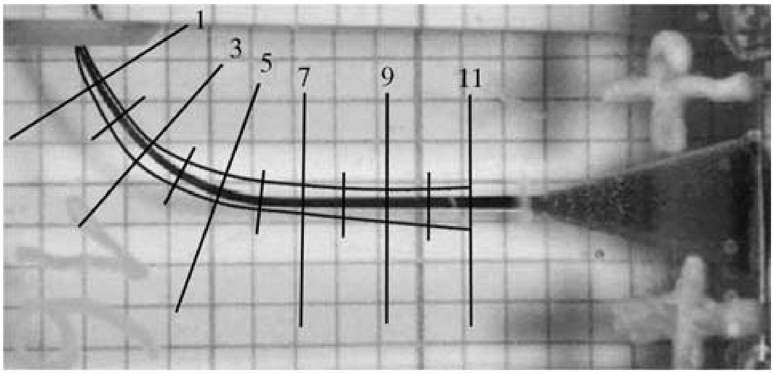

Figure 5 Photo of the untreated canal with a tracing of the mean amount of material removed by hand instrumentation. The figures denote the distance of the measuring points from the apical foramen (AF).

($P < 0.05\%$) more often after manual than after mechanical preparation (Table 6).

Root-canal transportation

Eighty per cent of the manually prepared canals were transported at the '1-mm' measuring point; the difference from those prepared with rotary files was significant ($P < 0.001$). Significant differences also were found at the 3-, 5-, 9- and 11-mm measuring points. Only the proportion of transportations at the 7-mm measuring point was not significantly higher with manual than with rotary preparation (Figs 4 and 5; Table 7).

Instrument fracture

Two of the Flexicut® files used in manual preparation fractured during preparation, whilst 14 FlexMaster® files used for rotary preparation were found to have failed. This difference was significant ($P < 0.05$).

Only one fracture occurred during preparation of the first root canal by the students. Eight fractures occurred during preparation of the fifth canal (Fig. 6).

Table 6 Assessment of the apical foramen (AF)

	Manual (SS) (%)	Rotary (Ni–Ti) (%)	*P*-values
AF intact	23.8	57.1	<0.01
AF mechanically instrumented	34.3	23.8	NS
AF blocked	41.9	19.1	<0.05

Preparation time

The mean time taken for preparation of the root canals was 24 min (24 ± 9.1 min) with the hand technique versus 12 min (12 ± 5.6 min) with the rotary technique. This difference was significant ($P < 0.001$) (Fig. 7).

Students' questionnaires

In reply to the question: 'Which of the methods did you find easier to learn?', one student marked answer '(a) hand preparation'; 17 '(b) engine-driven technique' and three '(c) both the same'.

In reply to the second question: 'Which system gave you a greater sense of security in its application?', only one student marked '(a) hand preparation'; 19 marked '(b) engine-driven technique' and one '(c) both the same'.

In reply to the third question: 'What kind of preparation would you select as a focal point of your dental education?', four students marked '(a) hand preparation'; three '(b) engine-driven technique' and 14 '(c) both methods equally'.

Group A versus group B (practice effect)

Whether learning a hand preparation technique prior to performing mechanical canal preparation could enhance the quality of the rotary preparation was evaluated. Group A had gained experience in manual preparation, whilst group B had not (Table 1).

Table 7 Transportation of the canal

Distance of measuring points from apex (mm)	Transported canals with hand preparation (%)	Transported canals with rotary preparation (%)	Direction of transportation in the canal	*P*-value
1	80.0	23.8	OPW	<0.001
3	56.2	19.0	OPW	<0.001
5	34.3	9.5	IPW	<0.01
7	26.7	16.2	IPW	NS
9	24.8	7.6	OPW	<0.001
11	29.5	6.7	OPW	<0.001

IPW, inner post-instrumentation width; OPW, outer post-instrumentation width.

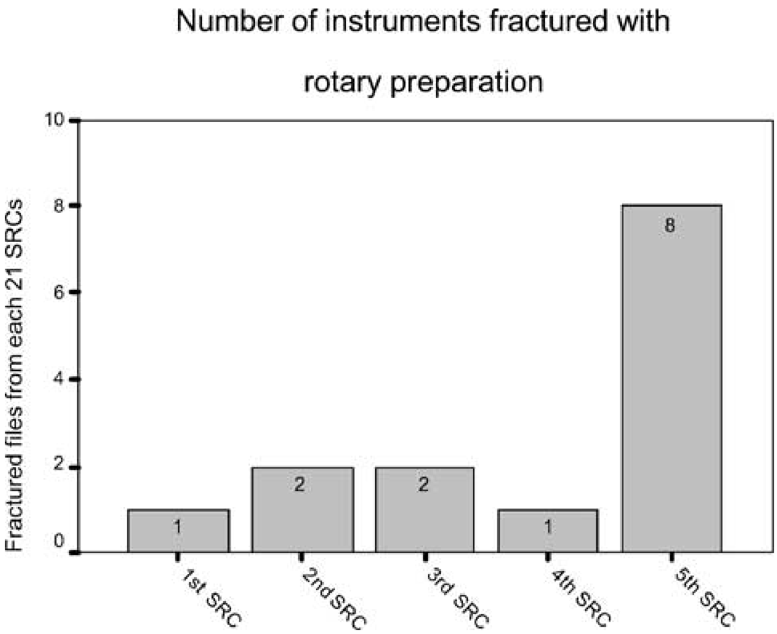

Figure 6 Number of fractures from each 21 prepared SRCs in the sequence first to fifth prepared canal. One block corresponds to a fracture rate of 4.76%.

Aberrations

The proportion of zips recorded in group B was not significantly above that recorded in group A. Nor did the number of elbows and ledges produced in group B differ significantly from that of group A (Table 8).

Preparation lengths

In group B, the number of master points (MP) attaining the correct preparation length was not significantly higher than in group A. Nor were there any significant differences in the number of MP that were too short or too long (Table 8).

Assessment of the apical foramen

An intact, nonblocked apical foramen was recorded insignificantly more frequently in group B than in group A. Apical foramens with traces of mechanical filing were found in 8.0% of all blocks prepared in group B. The

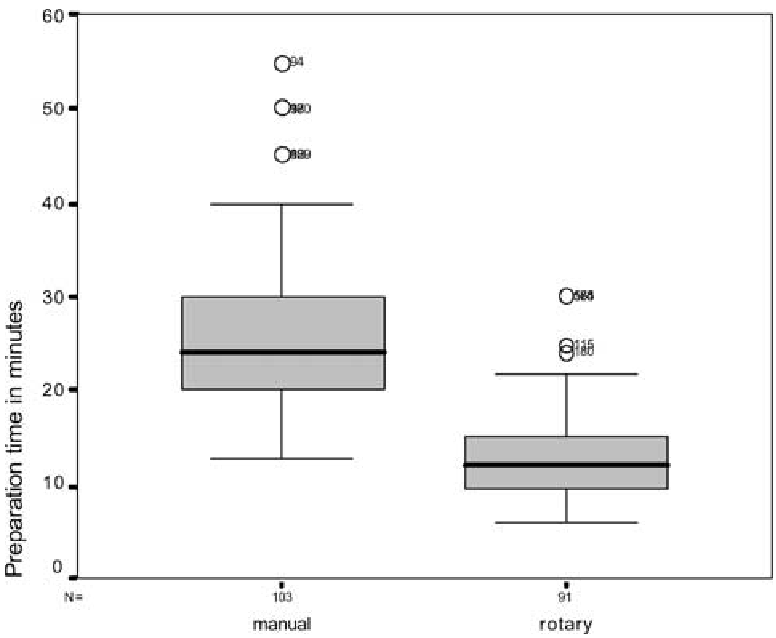

Figure 7 Evaluation of the time taken for manual and mechanical preparation in minutes.

Table 8 Evaluation of rotary preparation with and without experience in hand preparation

Investigation parameter	Group B Rotary preparation without experience in manual technique (%)	Group A Rotary preparation with experience in manual technique (%)	*P*-values
Zip	18.0	1.8	NS
Elbow	20.0	14.5	NS
Ledge	0.0	3.6	NS
MP correct	83.9	76.4	NS
MP too short	0.0	7.2	NS
MP too long	0.0	5.5	NS
AF intact	70.0	45.5	NS
AF injured	8.0	38.1	<0.05
AF blocked	22.0	16.4	NS
TrMsPt 1 mm	26.0	21.8	NS
TrMsPt 3 mm	30.0	9.1	NS
TrMsPt 5 mm	10.0	9.1	NS
TrMsPt 7 mm	22.0	10.9	NS
TrMsPt 9 mm	14.0	1.8	NS
Tr MsPt 11 mm	6.0	7.3	NS
Fracture rate	16.1	10.9	NS
	Time (mean ± SD)	Time (mean ± SD)	
Preparation time	12.5 ± 5.2 min	10.0 ± 5.9 min	<0.05

MP, master point; AF, apical foramen; TrMsPt, transportation measure point.

difference from the value recorded in group A was significant ($P < 0.05$). However, there was no significant intergroup difference in the number of blocked apical foramens (Table 8).

Root-canal transportation

At none of the measuring points (1, 3, 5, 7, 9 and 11 mm) was a significant difference recorded between groups A and B ($P > 0.05$) (Table 8).

Fractures of Ni–Ti instruments

The number of fractures recorded in the FlexMaster® files used was not significantly higher in group A than in group B (Table 8).

Preparation time

The mean time taken to prepare a root canal did not differ significantly between groups A and B (Table 8).

Discussion

To minimize the influence of the individual operator, the present study was performed with all students from one specific term in a crossover design. In this way, the methods were used both by less manually skilled and by highly manually skilled students.

Simulated canals were used for root canal preparation. These canals were selected because the size, conicity, curvature and material characteristics were identical in all canals and good comparability of the results was to be expected. Lim & Webber (1985) concluded that simulated canals were a valid model for experimental investigations concerning canal preparation.

For manual preparation, Flexicut® files were used, as they have a noncutting tip and triangular cross sections. For rotary preparation, Ni–Ti files with a convex cross-sectional profile were selected (Fig. 8). The FlexMaster® files have a noncutting tip and a negative rake angle

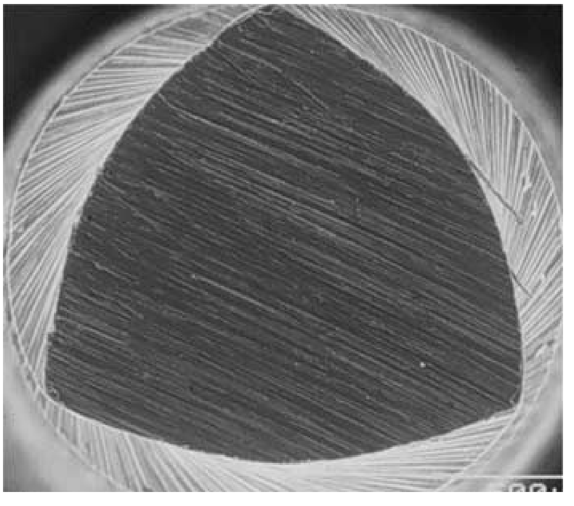

Figure 8 Cross section of a FlexMaster® file under SEM. Note the convex profile.

(approx. 35°). Turpin *et al.* (2000) reported that (triple helical) files with a larger instrument diameter than U-shaped files were far more resistant to torsion.

Investigations relating to preparation length showed that the therapeutic outcome of infected canals is most successful when the root filling ends 0–2 mm from the radiographic apex. Fillings extending beyond the apex or ending more than 2 mm from the radiological apex had a less successful therapeutic outcome (Sjogren *et al.* 1990, Wu *et al.* 2000).

Whereas the apical patency concept is taught at 50% of US dental schools (Cailleteau & Mullaney 1997), it is not widespread at European universities. The efficiency of debris removal in the techniques was verified by investigating the proportion of blocked, instrumented and intact apical foramena.

Superimposition of the images allowed the transportation of the severely curved SRCs to be precisely determined. Canal transportation at 1-, 3-, 5-, 7-, 9- and 11-mm measuring points invariably occurred in only one direction typical of the measuring point (Figs 4 and 5).

The times noted independently by the students for the duration of root canal preparation (without preflare) were taken as reference values. A high-precision time specification in scientific terms could not be assumed, as not only measuring errors by students but also group-dynamic processes might have had an impact on the time recorded for preparation.

In a comparative investigation between Ni–Ti and SS files, Esposito & Cunningham (1995) recorded significant differences only from an instrument diameter in excess of size 30. In the present study, preparation of the root canals was performed with instruments up to size 35.

The results of the present study confirm the first hypothesis formulated in the objectives, that is, mechanical root canal preparation with rotary FlexMaster® Ni–Ti files enabled inexperienced operators to achieve better maintenance of the original canal shape than manual preparation with Flexicut® stainless steel K-files.

Zips and elbows were recorded far less frequently with mechanical than with manual preparation. Root-canal transportations were registered far less frequently at the 1-, 3- and 11-mm measuring points with the rotary than with the hand technique. Transported canals were also recorded less frequently at the 5- and 9-mm measuring points than with manual preparation. The discrepancy between the two systems can be attributed to the higher flexibility of the Ni–Ti files. On the other hand, it has to be noted in criticism that the students had only little experience in the two techniques. Being more difficult to learn, the manual technique may therefore have produced poorer results than would have been the case with more experienced students. This issue has yet to be investigated. Although all simulated root canals were prepared by the students under supervision, substantial differences were observed between the manual and the engine-driven technique.

The fracture rate with mechanical preparation was above a clinically acceptable level. An examination of the files revealed not only fatigue fractures but also torsion fractures, some of which had even occurred in the shaft area of the files. It has to be assumed that some files were incorrectly used by the inexperienced students. Another finding characteristic of inexperienced handling of root canal instruments is the fracture rate recorded for the files used for manual preparation.

The results also confirm the second hypothesis, that is, experience in a manual preparation technique is not reflected in an improved quality of mechanical canal preparation.

The results set out in Table 6 show that the manual preparation of six curved root canals had a significantly positive impact on mechanical preparation in almost none of the points investigated. The only exception was the preparation time: The students prepared a curved root canal 2.5 min faster on average than those without preliminary manual practice. The AF was instrumented significantly more often by those students who had learned the manual technique first. This observation might be due to the instrumentation manner applied as a result of the experience gained in manual preparation.

Conclusions

The introduction of root canal preparation with rotary Ni–Ti files makes for significantly improved canal preparation in the teaching of inexperienced students. However, a number of FlexMaster® instruments fractured during the shaping procedure. Further *in vitro* investigations are indicated prior to the introduction of rotary preparation into undergraduate dental education.

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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.

Cailleteau JG, Mullaney TP (1997) Prevalence of teaching apical patency and various instrumentation and obturation techniques in United States dental schools. *Journal of Endodontics* **23**, 394–6.

Esposito PT, Cunningham CJ (1995) A comparison of canal preparation with nickel–titanium and stainless steel instruments. *Journal of Endodontics* **21**, 173–6.

European Society of Endodontology (2001) Undergraduate curriculum guidelines for endodontology. *International Endodontic Journal* **34**, 574–80.

Fouad AF, Burleson JA (1997) Effectiveness of an endodontic diagnosis computer simulation program. *Journal of Dental Education* **61**, 289–95.

Gambill JM, Alder M, del Rio CE (1996) Comparison of nickel–titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics* **22**, 369–75.

Garip Y, Gunday M (2001) The use of computed tomography when comparing nickel–titanium and stainless steel files during preparation of simulated curved canals. *International Endodontic Journal* **34**, 452–7.

Gluskin AH, Brown DC, Buchanan LS (2001) A reconstructed computerized tomographic comparison of Ni–Ti rotary GT files versus traditional instruments in canals shaped by novice operators. *International Endodontic Journal* **34**, 476–84.

Lim KC, Webber J (1985) The validity of simulated root canals for the investigation of the prepared root canal shape. *International Endodontic Journal* **18**, 240–6.

Luiten DJ, Morgan LA, Baugartner JC, Marshall JG (1995) A comparison of four instrumentation techniques on apical canal transportation. *Journal of Endodontics* **21**, 26–32.

Mandel E, Adib-Yazdi M, Benhamou LM, Lachkar T, Mesgouez C, Sobel M (1999) Rotary Ni–Ti profile systems for preparing curved canals in resin blocks: influence of operator on instrument breakage. *International Endodontic Journal* **32**, 436–43.

Marques MD, Moreira B, Eriksen HM (1998) Prevalence of apical periodontitis and results of endodontic treatment in an adult, Portuguese population. *International Endodontic Journal* **31**, 161–5.

Namazikhah MS, Mokhlis HR, Alasmakh K (2000) Comparison between a hand stainless-steel K file and a rotary NiTi .04 taper. *Journal of the Californian Dental Association* **28**, 421–6.

Pettiette MT, Delano EO, Trope M (2001) Evaluation of success rate of endodontic treatment performed by students with stainless-steel K-files and nickel–titanium hand files. *Journal of Endodontics* **27**, 124–7.

Pettiette MT, Metzger Z, Phillips C, Trope M (1999) Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel–titanium hand files. *Journal of Endodontics* **25**, 230–4.

Plasschaert AJ, Cailleteau JG, Verdonschot EH (1997) The effect of a multimedia interactive tutorial on learning endodontic problem-solving. *European Journal of Dental Education* **1**, 66–9.

Pruett JP, Clement DJ, Carnes DL Jr (1997) Cyclic fatigue testing of nickel–titanium endodontic instruments. *Journal of Endodontics* **23**, 77–85.

Qualtrough AJ, Whitworth JM, Dummer PM (1999) Preclinical endodontology: an international comparison. *International Endodontic Journal* **32**, 406–14.

Saunders WP, Saunders EM, Sadiq J, Cruickshank E (1997) Technical standard of root canal treatment in an adult Scottish sub-population. *British Dental Journal* **182**, 382–6.

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

Sjogren U, Hagglund B, Sundqvist G, Wing K (1990) Factors affecting the long-term results of endodontic treatment. *Journal of Endodontics* **16**, 498–504.

Turpin YL, Chagneau F, Vulcain JM (2000) Impact of two theoretical cross-sections on torsional and bending stresses of nickel–titanium root canal instrument models. *Journal of Endodontics* **26**, 414–7.

Weiger R, Hitzler S, Hermle G, Lost C (1997) Periapical status, quality of root canal fillings and estimated endodontic treatment needs in an urban German population. *Endodontics Dentistry Traumatology* **13**, 69–74.

Wu MK, Wesselink PR, Walton RE (2000) Apical terminus location of root canal treatment procedures. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **89**, 99–103.