Quality of preparation of oval distal root canals in mandibular molars using nickel-titanium instruments

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Abstract

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Aim The aim of this study was to compare the preparation of oval distal root canals in mandibular molars using three different nickel-titanium (NiTi) instruments: Lightspeed (Lightspeed Inc., San Antonio, TX, USA), ProFile .04 (Maillefer, Ballaigues, Switzerland) and Quantec SC (Tycom, Irvine, CA, USA).

Methodology Three groups of 20 extracted mandibular molars with oval distal root canals were embedded in a muffle system as described by Bramante *et al.* (1987) and modified by Hülsmann *et al.* (1999). Preparation of the root canals was performed with particular emphasis on the buccal and lingual extensions of the oval shape. The following parameters were evaluated: comparison of pre- and postoperative photographs with regard to the buccal and lingual extensions of the preparation, safety issues (file fractures, perforations, apical blockages, loss of working length), cleaning ability (SEM investigated using a 5-score system for remaining debris and smear layer) and working time.

Results Superimposition of pre- and postoperative cross-sections in the majority of specimens revealed uninstrumented or incompletely instrumented buccal or lingual extensions (Lightspeed and Quantec SC, 56.7%; ProFile .04, 55%). For debris removal, Quantec SC achieved the best results (54.2% scores 1 and 2), followed by ProFile .04 (52.5%) and Lightspeed (46.7%). Preparation resulted in substantial smear layer covering the canal walls for every system (ProFile .04, 38.3%; Quantec SC, 36.6%; Lightspeed, 28.3%). Differences between the three systems were not significant for any of the parameters investigated. Preparation with Lightspeed resulted in two fractured instruments; with Quantec SC, two apical blockages occurred. With ProFile .04, no complications were noticed. Mean working time was shorter for ProFile .04 (261.2 s) than for Quantec SC (272.4 s) and Lightspeed (338.9 s); the differences were not significant.

Conclusions The flexibility of the NiTi instruments investigated in this study did not allow controlled preparation of the buccal and lingual extensions of oval root canals. The instruments frequently produced a circular bulge in the canal whilst the buccal and lingual extensions remained unprepared, leaving smear layer and debris.

Keywords: canal cleanliness, canal shape, nickel-titanium rotary instruments, root canal preparation.

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Introduction

The main parameters in evaluation of any technique or device for root canal preparation are the ability to enlarge and clean the root canal sufficiently. Additionally, good working safety should be a main prerequisite for the use of any instrument or technique. Numerous investigations have demonstrated the ability of several new rotary nickel-titanium (NiTi) systems to maintain original curvature of mesial root canals of mandibular molars (Thompson & Dummer 1997a,b,c,d, 1998[a],b, Peters *et al.* 1998, Hülsmann *et al.* 2001, Versümer *et al.* 2002). NiTi instruments have a two to three times higher

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elastic flexibility ('superelasticity' and 'memory shape') and a superior resistance to torsional fracture than conventional stainless steel instruments, which makes these instruments useful for the preparation of curved root canals (Walia *et al.* 1988). No data on NiTi preparation of slightly curved but oval root canals could be found in the recent literature. Such cross-sections can often be found in the distal root canals of mandibular molars or in mandibular incisors (Wu *et al.* 2000). In an investigation of 180 teeth of all groups, Wu *et al.* (2000) detected oval canals in 25% of all sections investigated. Difficult areas for instrumentation and obturation are the buccal and lingual extensions of these irregular canals (Wu *et al.* 2000). Complete preparation with stainless steel instruments includes a high risk of perforating or significantly weakening the root. On the other hand, it seems questionable whether highly flexible NiTi instruments allow controlled preparation of such extensions. Due to limited efficacy of irrigation in such recesses, debris and smear layer may accumulate and remain on these unprepared root canal walls, decrease the quality of obturation and jeopardize the long-term treatment success.

The aim of the present study was to evaluate several parameters of automated root canal preparation using ProFile .04 (Maillefer, Ballaigues, Switzerland), Quantec SC (Tycom, Irvine, CA, USA) and Lightspeed (Lightspeed Inc., San Antonio, TX, USA) rotary NiTi instruments on oval distal root canals of mandibular molars. The parameters evaluated were: postoperative root canal diameter, root canal cleanliness, incidence of procedural errors such as file fractures and perforations, loss of working length and working time.

Materials and methods

Preparation of teeth

A modification of the Bramante technique (Bramante *et al.* 1987, Hülsmann *et al.* 1999) was used to evaluate simultaneously the cleaning ability as well as cross-sectional preparation form, safety issues and working time on extracted teeth under conditions comparable to the clinical situation. A muffle block was constructed, consisting of a u-shaped middle section and two lateral walls which are fixed together with three screws. Grooves in the walls of the muffle block allowed removal and precise repositioning of the complete tooth block or sectioned parts of the tooth.

Sixty extracted mandibular molars with intact roots and apices were used in this study. Following preparation of standard access cavities, the distal root canals were controlled visually for oval shape at the root canal orifice and with a size 10 reamer for apical patency. Only teeth with a bucco-lingual distance twice as long as the mesio-distal distance and root canal curvatures less than 20° were included into the study. All teeth were shortened to a length of 19 mm, mounted into the mould with acrylic resin and isolated with rubber dam and a clamp, simulating the clinical situation and ensuring that the operator could gain access to the root canal only from the mesial direction.

The embedded teeth were sectioned horizontally at 3, 6 and 9 mm from the apex and the preoperative shape of the distal root canals were photographed under standardized conditions and the segments remounted into the mould. The teeth were randomly divided into three groups for preparation with ProFile .04 (Maillefer, Ballaigues, Switzerland), Quantec SC (Tycom, Irvine, CA, USA) and Lightspeed (Lightspeed Inc., San Antonio, TX, USA) NiTi rotary instruments.

Instruments and preparation techniques

ProFile .04

In the present study, root canal preparation was performed in the following step-down sequence: ProFile .04 size 25, 14 mm; size 30, 14 mm; size 20, 16 mm; size 15, working length (18 mm) and sizes 20–45, working length (18 mm). The total number of instruments used was 10.

Lightspeed

Preparation with Lightspeed instruments was performed using a step-back technique (Wildey & Senia 1989). The sequence of instruments used in this study was the one proposed by the manufacturer: Hand instrument size 15, working length (18 mm); Lightspeed instruments sizes 20–45, working length (18 mm) and sizes 47.5–70, step-back with each instrument used 1 mm shorter than the last one. The total number of instruments (including size 15 hand-file) used was 20.

Quantec SC

Root canal preparation with Quantec SC instruments was performed using a step-down technique: instrument no. 1 (25/.06), 15 mm; no. 2 (15/.02); no. 3 (20/.02); no. 4 (25/.02), working length (18 mm); no. 5–8 (25/.03–.06), working length (18 mm); no. 9 (40/.02) and no. 10 (45/.02), 17 mm. The total number of instruments used was 10.

All root canals were prepared with a dental hand piece in a low-speed, high-torque motor with torque control

(TCM 3000, Nouvag, Konstanz, Germany). Preparation speed was 250 r.p.m. for ProFile .04, 1300 r.p.m. for Lightspeed and 340 r.p.m. for Quantec SC as proposed by the manufacturers. The preparation of the oval distal root canals was performed shaping especially the buccal and lingual extensions. Irrigation was performed with 2 mL NaOCl (3%) after each instrument size in the ProFile .04 and Quantec SC group, and after each second instrument in the Lightspeed group. RC-Prep (Premier, Norristown, PA, USA) was used as a chelating agent with each instrument. Instruments were discarded after preparation of 10 root canals. Apical patency was controlled using an ISO 10 reamer extending 1 mm beyond working length following each instrument size.

Assessment of preparation

After preparation, the cross-sections of the distal root canals were photographed again. The divergence of pre- and postoperative root canal diameter was evaluated by superimposing pre- and postoperative canal outlines.

Following preparation, the cross-sections were removed from the mould and the three root segments were freed from the resin. From the mesial direction, two grooves were cut into the root and a v-shaped segment of the root could be removed so that the buccal and lingual extensions could be examined under the SEM (Fig. 1 a,b). The roots were coded and mixed so that

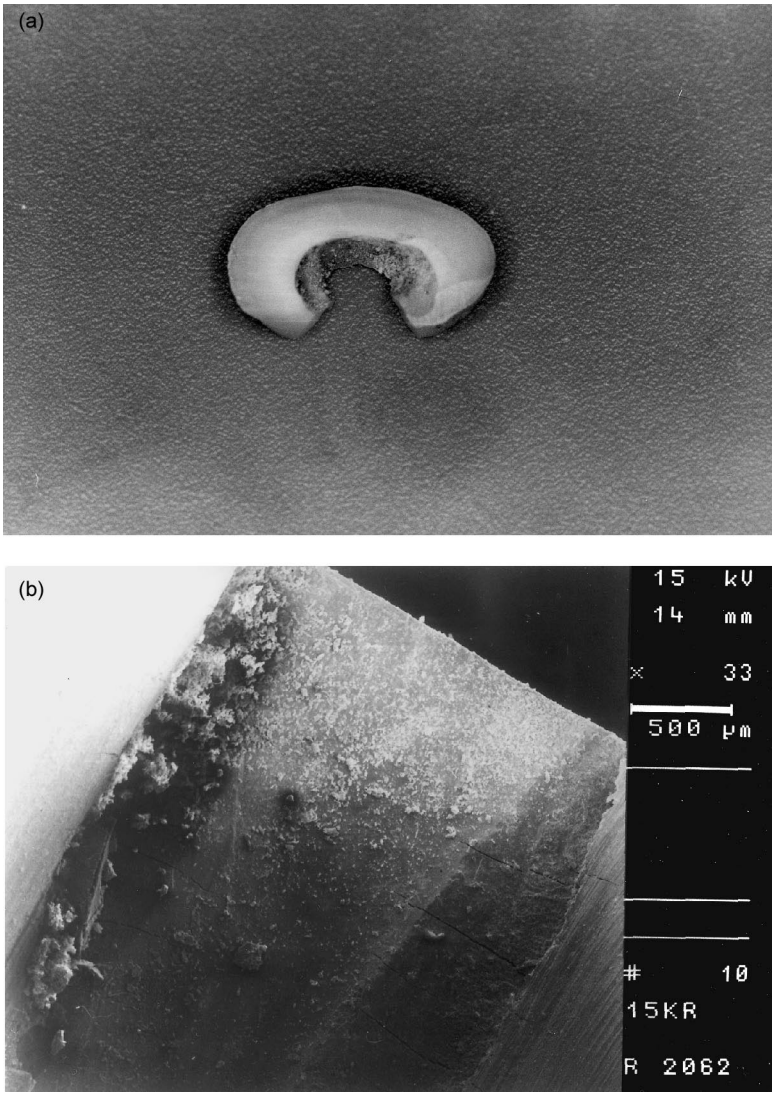

Figure 1 (a) Specimen prepared for SEM investigation. A segment was removed from the mesial root canal wall allowing investigation of the buccal and lingual recesses. (b) View into a buccal recessus under the SEM (magnification: 33×).

the type of instrument used for preparation could not be identified during SEM investigation.

Separate evaluations were undertaken for debris and smear layer with a 5-score system. For each score system, the same set of reference photographs were used as in previous investigations (Hülsmann *et al.* 1997, 2001, Versümer *et al.* 2002). Cleanliness was evaluated only in the buccal and lingual extensions of the canals. Debris was defined as dentine chips, pulp remnants and particles loosely attached to the root canal wall.

- *Score 1*: Clean root canal wall, only few small debris particles.
- *Score 2*: Few small isles of debris.
- *Score 3*: Many accumulations of debris covering less than 50% of the root canal wall.
- *Score 4*: More than 50% of the root canal wall covered by debris.
- *Score 5*: Complete or nearly complete root canal wall covered by debris.

Scoring of debris was performed using 200× magnification.

Smear layer was defined as proposed by the 'American Association of Endodontists' glossary 'Contemporary Terminology for Endodontics' (1994): a surface film of debris retained on dentine or other surfaces after instrumentation with either rotary instruments or endodontic files, consists of dentine particles, remnants of vital or necrotic pulp tissue, bacterial components and retained irrigant.

- *Score 1*: No smear layer, dentinal tubules open.
- *Score 2*: Small amount of smear layer, some dentinal tubules open.
- *Score 3*: Homogeneous smear layer covering the root canal wall, only few dentinal tubules open.
- *Score 4*: Complete root canal wall covered by homogeneous smear layer, no open dentinal tubules.
- *Score 5*: Heavy, inhomogeneous smear layer covering the complete root canal wall.

Smear layer was scored under 1000× magnification.

After the central beam of the SEM had been directed to the centre of the object by the SEM operator (F.S.) under 10× magnification, the magnification was increased to 200 and 1000×, respectively, and the canal wall region appearing on the screen was scored. The scoring procedure was performed by a second operator (M.H.) who could not identify the coded specimens. This operator had been trained in the scoring procedure, resulting in a sufficient intraobserver reproducibility (Hülsmann *et al.* 1997).

Statistical analysis

For comparison of the cross-sections, root canal cleanliness and working time, the Kruskal–Wallis test ($P < 0.05$) was used.

Results

The results of the analysis of the photographs of the canal cross-section and their buccal and lingual extensions are detailed in Table 1. In the unprepared segments of the buccal extensions, Lightspeed and ProFile .04 with 15% obtained a worse result than Quantec SC with 13.3%. Concerning the unprepared segments of the lingual extensions, the following ranking resulted: Lightspeed (28.3%), ProFile .04 (25%) and Quantec SC (13.3%).

Superimposition of the photographs of the cross-sections of the pre- and postoperative root canal shapes showed that all three systems left uninstrumented areas in many cases. Only 10 (Lightspeed), 19 (Quantec SC) and 21 (ProFile .04) specimens out of 60 per group showed no contact between the pre- and postoperative root canal outlines, indicating limited circumferential instrumentation of the root canal wall (Table 2). The best results were recorded in the apical third. Overall Lightspeed demonstrated 46 of 60 specimens showing 0–25% contact between pre- and postoperative diameter, followed by ProFile .04 (45 specimens) and Quantec SC

Table 1 Prepared and unprepared areas of canals in the buccal and lingual extensions of oval canals by instrument

	Lightspeed				ProFile .04				Quantec SC			
Extension	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
Buccal												
Prepared	13	18	20	51 (85%)	17	16	18	51 (85%)	13	19	20	52 (86.7%)
Unprepared	7	2	0	9 (15%)	3	4	2	9 (15%)	7	1	0	8 (13.3%)
Lingual												
Prepared	12	13	18	43 (71.7%)	11	15	19	45 (75%)	16	18	18	52 (86.7%)
Unprepared	8	7	2	17 (28.3%)	9	5	1	15 (25%)	4	2	2	8 (13.3%)
n				120				120				120

Table 2 Contact between pre- and postoperative cross-section

Contact between pre- and postoperative cross-section	Lightspeed				ProFile .04				Quantec SC			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
0%	1	2	7	10	7	4	10	21	6	5	8	19
0–25%	11	13	12	36	9	11	4	24	10	5	5	20
>25%	8	3	1	12	3	3	3	9	3	6	4	13
>50%	0	2	0	2	1	1	3	5	1	3	2	6
>75%	0	0	0	0	0	1	0	1	0	0	2	2
n				60				60				60

Table 3 Assessment of root canal cleanliness (buccal and lingual extensions are combined)

	Lightspeed				ProFile .04				Quantec SC			
	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total	Coronal	Middle	Apical	Total
Debris												
Score												
1	5	10	10	25 (21.7%)	10	4	16	30 (26.3%)	8	8	11	27 (22.5%)
2	7	12	12	31 (27.0%)	7	15	11	33 (28.9%)	8	15	15	38 (31.7%)
3	10	8	4	22 (19.1%)	3	9	7	19 (16.7%)	8	9	9	26 (22.8%)
4	1	3	4	8 (7.0%)	4	3	1	8 (7.0%)	2	3	2	7 (5.8%)
5	0	1	1	2 (1.7%)	1	0	1	2 (1.7%)	2	1	1	4 (3.3%)
Unprepared	15	7	5	27 (5.2%)	11	9	2	22 (19.3%)	12	4	2	18 (15.0%)
Loss of specimen	2	0	3	5	4	0	2	6	0	0	0	0
Smear layer												
Score												
1	4	6	2	12 (10.4%)	5	2	1	8 (7.0%)	4	3	0	7 (5.8%)
2	10	7	10	27 (5.2%)	7	7	7	21 (18.4%)	8	6	6	20 (16.7%)
3	5	16	13	34 (29.6%)	7	16	23	46 (40.3%)	8	18	18	44 (36.7%)
4	4	4	5	13 (11.3%)	5	4	3	12 (10.5%)	4	5	12	21 (17.5%)
5	0	1	1	2 (1.7%)	1	2	2	5 (4.4%)	4	4	2	10 (8.3%)
Unprepared	15	7	5	27 (5.2%)	11	9	2	22 (19.3%)	12	4	2	18 (15.0%)
Loss of specimen	2	0	3	5	4	0	2	6	0	0	0	0

(39 specimens). No statistically significant differences could be found between the instruments (Kruskal–Wallis test: apical, $P = 0.4157$; middle, $P = 0.6885$; coronal, $P = 0.0727$).

Root canal cleanliness

Following longitudinal splitting of the 60 root segments per group, the buccal and lingual specimens were analysed for cleanliness of the buccal and lingual extensions using the SEM. Some specimens could not be evaluated because of technical difficulties. The results of the SEM analysis of the root canal walls are shown in Table 3.

Generally, the root canals showed no homogeneous appearance. Some specimens (ProFile .04, 30 out of 114 (26.3%); Quantec SC, 27 out of 120 (22.5%) and Lightspeed, 25 out of 115 (21.7%)) showed completely clean walls without any remaining debris (score 1). Most canals received a score 2 (Quantec SC, 38 (31.7%); ProFile .04, 33 (27.5%) and Lightspeed, 31 (25.8%)). A total of 67 of 349 evaluated specimens (19.2%) root canal segments remained unprepared. No statistically significant differences between the three systems were found for remaining debris in the apical, middle and coronal segments respectively (Kruskal–Wallis test: buccal extensions – apical, $P = 0.3963$; middle, $P = 0.5521$; coronal, $P = 0.5666$; lingual extensions – apical, $P = 0.4595$; middle, $P = 0.5710$; coronal, $P = 0.9353$).

Lightspeed preparation resulted in 12 out of 115 (10.4%) surfaces without smear layer (score 1), ProFile .04 in eight out of 114 (7.0%) and Quantec SC in seven out of 120 (5.8%). A high number of specimens within each group were rated score 3 (ProFile .04, 40.3%;

Quantec SC, 36.7%; Lightspeed, 29.6%). Unprepared root canal walls were detected in 67 of 349 (19.2%) evaluated specimens with most of them in the Lightspeed group (27 of 115, 23.5%). ProFile .04 preparation resulted only in 22 out of 114 (19.3%), Quantec SC in 18 out of 120 (15.0%) specimens with completely unprepared extensions. Differences between the systems were not significant (Kruskal–Wallis test: buccal extensions – apical, $P = 0.3312$; middle, $P = 0.4052$; coronal, $P = 0.8013$; lingual extensions – apical, $P = 0.4321$; middle, $P = 0.4546$; coronal, $P = 0.4254$).

Procedural errors

ProFile .04 preparation proved to be a safe technique with no instrument fracture, perforation, apical blockage and cases with loss of working length. With the Lightspeed system, two fractures (sizes 35 and 42.5) occurred, but both instruments could be removed from the canals. No perforation, apical blockage and case of loss of working length were observed. With the Quantec SC system, two apical blockages occurred after preparation with the second instrument.

Working time

Measurement of working time, not including time for instrument changes and irrigation, resulted in a median of 195.7 s for ProFile .04 instrumentation (10 instruments), 206.9 s for Quantec SC (10 instruments) and 208 s for the Lightspeed system (20 instruments). Differences between the systems were not significant (Kruskal–Wallis-test: $P = 0.4534$). Including time for irrigation, the root canal preparation resulted in the following median working times (Lightspeed, 338.9 s; Quantec SC, 272.4 s; ProFile .04, 261.2 s).

Discussion

Comparison of different root canal preparation systems requires standardized conditions and the collection of data on all important aspects of performance for a definite conclusion on the clinical usefulness of a rotary device to be determined. In this study, several parameters such as postoperative root canal shape, cleanliness, working safety and working time were investigated. This study is one of a series of investigations on different rotary NiTi instruments that should allow a comparison of all the major NiTi systems. In this series of studies (Hülsmann *et al.* 2001, Versümer *et al.* 2002), mesial root canals of extracted mandibular molars were used. A similar series of investigations on rotary NiTi systems has been undertaken by the group of Thompson & Dummer (Thompson & Dummer 1997a,b,c,d, [1998a],b) using artificial root canals in resin blocks with specific curvatures. The advantages of such simulated root canals are a standardized canal form and reproducible conditions. The disadvantages of plastic blocks such as the difference between the hardness of dentine and the plastic as well as the abrasion behaviour have been described (Lim & Webber 1985, Miserendino *et al.* 1988). In the present study, root canal preparation was performed in extracted teeth to evaluate parameters such as the appearance of the dentinal surface and the accumulation of smear layer and debris. On the other hand, parameters such as degree, angle and location of root canal curvature, initial diameter of the root canal and shape of the cross-section were standardized. However, the shape of the cross-section at the root canal orifice was controlled optically. Only teeth with a bucco-lingual distance twice as long as the mesio-distal distance were included into the study which is similar to the criteria used by Wu *et al.* (2001) and Wu & Wesselink (2001), who investigated only teeth with an internal long : short diameter ratio of >1.6 and >2, respectively.

Cross-sections

The aim of the present study was to examine whether the buccal and lingual extensions of oval root canals could be prepared completely with highly flexible NiTi instruments. The comparison of the pre- and postoperative photographs of root canal cross-sections enables the extent of dentine removal to be evaluated quantitatively and qualitatively. Bramante *et al.* (1987) were the first to develop a method for the evaluation of changes in root canal diameter. Using a modification of their method, pre- and postinstrumentation photographs of the root canal diameter may be superimposed and deviations between the two root canal outlines can be measured. As the diameter of a root canal is not constant from the orifice to the apex, the roots were sectioned horizontally at 3, 6 and 9 mm from the apex, respectively, allowing inspection of all thirds of a root canal.

Superimposition of photographs of the pre- and postinstrumentation cross-sectional forms revealed that all three systems showed the best results in the apical third with only a few sections having unprepared lingual or buccal extensions. This, of course, is due to the fact that most oval distal root canals become more round towards the apical third of the root; this has been confirmed in

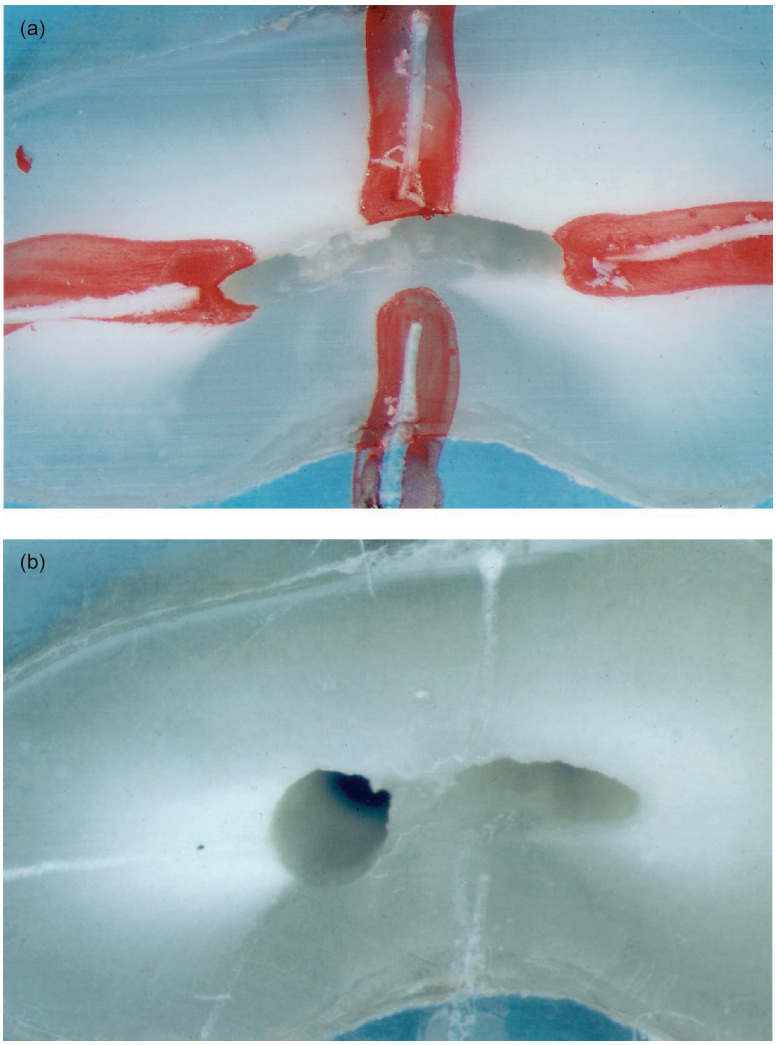

Figure 2 (a) Cross-section before preparation. (b) Postoperative cross-section showing an unprepared lateral extension and an irregular canal shape.

a recent study on extracted teeth (Wu *et al.* 2000). Preparation with ProFile .04 was superior in the apical region compared to Lightspeed and Quantec SC (Table 2), but in all three parts of the root canals, no significant differences between the three NiTi systems could be found. The middle and coronal cross-sections were increasingly irregular and frequently showed circular bulges (Fig. 2 a,b). All three systems performed relatively poorly in these two sections of the root canals, probably because of their flexibility, frequently not allowing the operator to force them into the lateral extensions. The design of the instruments with safe tips and radial land may have resulted in a self-centering movement of the files along the initial lumen of the canal. The buccal and lingual extensions of the oval root canals therefore often remained unprepared, and a circular bulge somewhere in the centre of the root resulted (Fig. 3 a,b). The best results were obtained with Quantec SC instruments.

The total amount of noninstrumented canal areas was rather high (19.2%). It should be explained that in this study, Lightspeed instruments were used in a circumferential filing motion rather than a pecking motion as recommended by the manufacturers. Indeed, they recommend that oval canals should be treated as two canals with the buccal and lingual extension representing a separate canal. Preparation of these two canals is advised to a size when the two canals overlap in the middle of the root. In the recent literature, no data on postoperative cross-sections of distal root canals of lower molars could be found, but the findings are in accordance with the results of previous investigations by Wu & Wesselink (2001), who, following preparation of oval

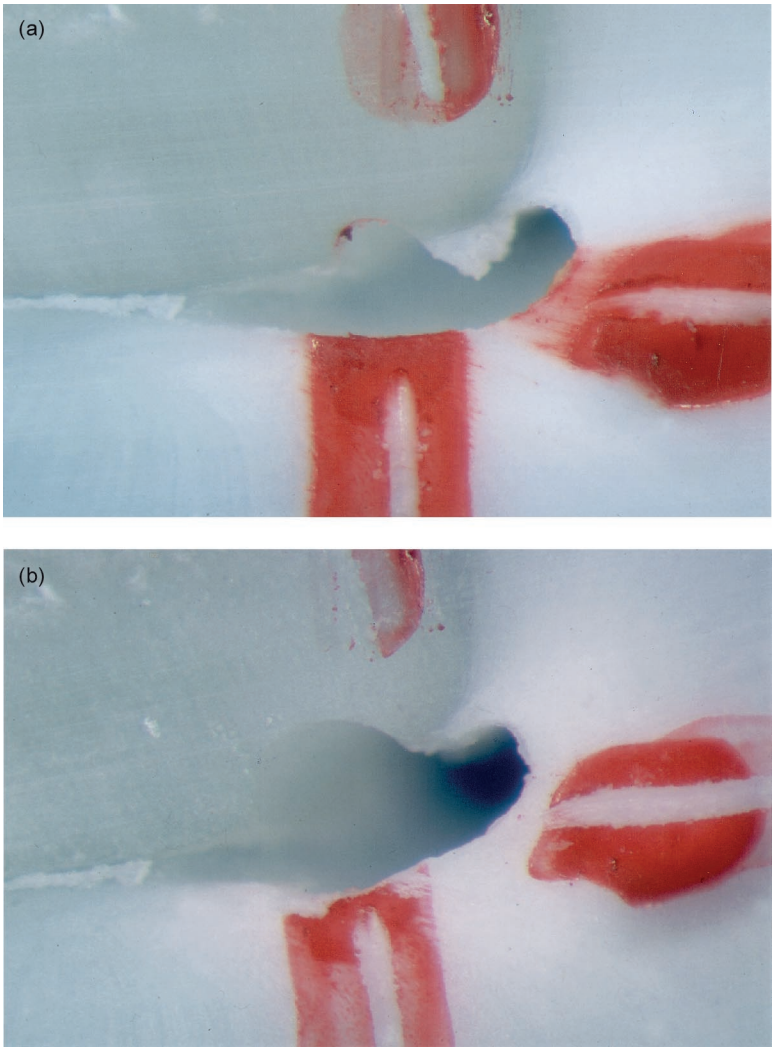

Figure 3 (a) Preoperative cross-section. (b) Postoperative cross-section showing a massive circular bulge with unprepared lateral extensions.

canals in mandibular incisors with the balanced force technique, reported uninstrumented extensions in 65% of the canals. In a recent study on the quality of root fillings in oval canals using extracted premolars, Wu *et al.* (2001) also found a high percentage of unprepared and unfilled buccal and lingual recesses. Barbizam *et al.* (2002) confirmed these findings in a study on preparation of flattened root canals in mandibular incisors.

Root canal cleanliness

In the present study, postoperative root canal cleanliness was investigated only for the buccal and lingual extensions of the oval canals. None of the three NiTi preparation techniques resulted in complete cleaning of these areas of the canal walls. The majority of the canals achieved a score of 2 for debris and a score of 3 for smear layer. No significant differences between the three techniques could be found. As all techniques had been used with an identical irrigation regimen, this tends to reflect the fact that the irrigation regimen is more responsible for canal cleanliness than preparation techniques or instruments. The SEM evaluation revealed that neither irrigants nor instruments could remove sufficient debris and smear layer from the recesses. In a comparative SEM study, ProFile .04 and Lightspeed were shown to be equally effective in the debridement of root canals (Peters *et al.* 1998). In previous studies, it was shown that the cleaning ability of ProFile .04 and Lightspeed was worse than for Quantec SC or HERO 642. Following preparation with HERO and Quantec, clean root canal walls without debris, no or minimal smear layer

and many open dentinal tubules could be frequently detected under the SEM (Hülsmann *et al.* 2001, Versümer *et al.* 2002). The main reason for the inferior cleaning ability of Lightspeed and ProFile .04 probably will be the radial lands of the instruments which have a planning action on the root canal wall rather than a cutting action as with Quantec SC and HERO 642. Medioni *et al.* (1999) confirmed the superior cleaning ability of Quantec SC when compared to HERO 642, ProFile .04 and hand instrumentation. On the other hand, Barbizam *et al.* (2002) reported superior results for the manual crown-down technique using stainless steel K-files compared to ProFile .04 rotary preparation of flattened root canals in mandibular incisors. In the present investigation, no significant differences between the three NiTi systems could be found. Cleanliness of recesses in oval canals may be enhanced by use of sonic or ultrasonic irrigation techniques which remove debris but do not affect the smear layer when only used with water as irrigant. Therefore, sodium hypochlorite or chelating agents such as EDTA should be selected. When an ultrasonic unit is used for irrigation, the file is best directed towards the extensions (Lumley *et al.* 1993).

Working safety

Generally, many authors reported on the fact that NiTi instruments fracture more frequently when forced with variable speed of rotation, overuse of instruments and excessively high rotational speed (Barbakow & Lutz 1997). Additionally, the operator's experience with specific systems may be related to the frequency of instrument fractures. As recommended by Gambarini (2000), the use of a low-torque endodontic motor with constant speed for each file of any NiTi system instead of a high-torque motor might help to reduce the risk of instrument fracture.

The Lightspeed system has been described to be safe for the preparation of curved root canals (Thompson & Dummer 1997a,b, Versümer *et al.* 2002). In the present study, two instruments fractured during the forced attempt of a circumferential filing motion which is not in accordance with the manufacturers' recommendation. In an evaluation of Thompson & Dummer (1997c,d), no fractures occurred with the ProFile .04 system.

Concerning the fracture frequency of Quantec SC instruments, little information is found in the literature. Thompson & Dummer (1998a) had one fractured and three deformed instruments. No apical blockages and loss of working length occurred in their study. In the present investigation, no fractures, but two apical blockages, could be detected. In recent studies on preparation of curved root canals using different NiTi instruments in 50 root canals, three instrument fractures, three apical blockages and eight cases of loss of working length occurred with the Quantec system (Hülsmann *et al.* 2001). Following preparation with ProFile .04, three instruments separated whereas no procedural errors occurred with the Lightspeed system (Versümer *et al.* 2002).

Working time

The finding that Lightspeed instrumentation took significantly more time than ProFile .04 and Quantec SC preparation to a large extent will be due to the fact that the number of files for the three systems greatly differs (Lightspeed, 20; ProFile .04 and Quantec SC, 10). Following the protocol of this study, the number of irrigations for Lightspeed was 12, ProFile .04 and Quantec SC 10. Clinically, the difference will be even more evident as time for instrument changes and adjustment of the stopper systems has to be added. On the other hand, preparation time for each single instrument was shorter for Lightspeed, due to the reduced contact zone between instrument and root canal wall.

Overall, the ability of NiTi systems to shorten working time compared to hand preparation or to automated root canal preparation using different endodontic hand pieces with conventional stainless steel files has already been confirmed in a number of previous studies (Esposito & Cunningham 1995, Hülsmann *et al.* 2001).

Conclusions

The flexibility of the three NiTi instruments evaluated in this study did not allow controlled preparation of the buccal and lingual extensions of oval root canals. The instruments frequently produced a circular bulge in the canal whilst the buccal and lingual extensions remained unprepared. Root canal cleanliness was not good with much remaining debris and smear layer in the unprepared extensions.

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