
Effects of rotary instruments and ultrasonic irrigation on debris and smear layer scores: a scanning electron microscopic study

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Abstract

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Aim This study evaluated debris and smear layer scores after two types of instruments manufactured from different alloys were used to ultrasonically activate irrigants during canal preparation. The influence of two rotary preparation techniques on cleanliness of the shaped canals was also studied.

Methodology Apical stops were prepared to size 45 in 42 single-canal extracted premolars and canines, which were divided into six equal groups. Groups 1, 2 and 3 were prepared by ProFile .04 (PF) while groups 4, 5 and 6 were prepared by Lightspeed (LS). All groups were irrigated using 5.25% NaOCl and 17% EDTA. Irrigants in groups 2 and 5 were ultrasonically activated using a size 15 steel K-file and by a blunt flexible nickel–titanium wire in groups 3 and 6. Groups 1 and 4 served as negative

controls. Roots were split and canal walls examined at 15×, 200× and 400× magnification in an SEM. Smear layer and debris scores were recorded at 3, 6 and 9 mm levels using a 5-step scoring scale and a 200-μm grid. Means were tested for significance using nonparametric Mann–Whitney *U* and Kruskal–Wallis tests.

Results Debris and smear layer scores for the six groups varied from 1.98 ± 1.04 to 3.47 ± 0.97 and from 1.37 ± 0.4 to 2.36 ± 0.99 , respectively. Although all groups had significantly higher smear layer and debris scores at the 3 mm levels compared to the 9 mm levels ($P < 0.05$), no significant differences were recorded due to the ultrasonic energy transmitted by the two alloys.

Conclusion Ultrasonically activated irrigants did not reduce debris or smear layer scores. This finding was not influenced by the material nor by the design of the instrument used to transmit ultrasonic activation.

Keywords: Debris, rotary preparation, smear layer, ultrasonic irrigation.

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Introduction

Irrigation during the cleaning and shaping of root canal systems is a critical component of endodontic therapy. Traditionally, irrigants are delivered by syringe and needle, with larger preparations facilitating their insertion. However, irrigants can only progress 1 mm further than the tip of the needle (Ram 1977). Larger apical canal shapes also improve debridement and disinfection of

canals (Abou-Rass & Piccinino 1982). However, thorough cleaning of the most apical part of any preparation remains difficult (Wu & Wesselink 1995).

Procedural errors such as zipping or ledging are likely to occur when canals are shaped using manual techniques, but the introduction of engine driven nickel–titanium instruments such as Lightspeed (Lightspeed Inc, San Antonio, TX, USA), ProFile (Dentsply Maillefer, Ballaigues, Switzerland) and Quantec (NT Company, Chattanooga, TN, USA) have minimized the incidence of such procedural errors. Preparations are better centred, working length is rarely lost and larger sized apical stops can be achieved (Thompson & Dummer 1997a, 1997b, Bryant *et al.* 1998a, 1998b). However, common to all types

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of cutting instruments, residual debris and smear layer is found on root canal walls after rotary preparation (Peters & Barbakow 2000).

The use of ultrasonic files to shape canals was accompanied by improved debridement (Cunningham & Martin 1982). However, ultrasonically activated stainless steel files tended to ledge and perforate canal walls (Sundqvist & Figdor 1998). Initial studies indicated that ultrasonic files produced significantly cleaner canal walls than specimens without the use of ultrasonic energy (Cunningham & Martin 1982). Furthermore, Krell *et al.* (1988) showed that freely oscillating files transported irrigants *in vitro* into the apical parts of the preparation.

In contrast, other experiments reported little or no difference in root canal debridement when using ultrasonic energy. This finding was particularly prevalent in curved and irregular canals in which remnants of pulp tissue, debris and smear layer were detected (Langeland *et al.* 1985, Lev *et al.* 1987, Cheung & Stock 1993, Heard & Walton 1997). However, these studies were carried out using different procedures and different techniques to evaluate debris and smear layer quantities.

The aim of this study was to evaluate whether the material and the geometric design of ultrasonic tips affected the debridement of root canals *in vitro* during irrigation. In addition, the influence of two engine-driven rotary preparation techniques on canal surface morphology was also examined.

Materials and methods

Forty-two single-rooted extracted human premolars and canines, each with one single root canal, were selected from the Department's pool of extracted teeth. The specimens were stored in 0.1% thymol solution throughout the experiment. The teeth were randomly numbered and equally divided into four test and two control groups. Access cavities were prepared using diamond burs (Intensiv, Bioggio, Switzerland) while Gates-Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) were used

for the step-down preparation. Patency of apical foramina was standardized using size 08 or 10 stainless steel K-Files (Dentsply Maillefer). Working lengths were set by deducting 1 mm from the lengths of the files when they extruded just beyond the apical foramina. Canals were shaped by Lightspeed or ProFile .04 instruments used according to the procedures established in the Department (Peters *et al.* 1997, Schrader *et al.* 1999). All preparations were carried out by the principal author. In all canals, apical stops were prepared to size 45 and irrigants were delivered using a 27-gauge needle (Braun, Melsungen, Germany) which was inserted as far into the prepared root as possible without binding.

Specimens in groups 1, 2 and 3 were prepared using ProFile instruments, while those in groups 4, 5, and 6 were prepared using Lightspeed instruments (Table 1). Canals in all groups were irrigated using 2 mL of a 5.25% NaOCl solution and 2 mL of a 17% EDTA solution, alternatingly, after each instrument. Groups 1 and 4 served as controls in which the irrigants were not ultrasonically activated. Final aliquots of EDTA and NaOCl were left *in situ* for 1 min before being flushed with NaOCl. In groups 2 and 5, aliquots of EDTA and NaOCl were left *in situ* for 1 min and were ultrasonically activated using a size 15 stainless steel K-file (Endosonore, Dentsply Maillefer, Fig. 1). A final flush with NaOCl concluded the preparation.

In groups 3 and 6, final aliquots of EDTA and NaOCl were left *in situ* for 1 min during which the irrigant was ultrasonically activated by a specially prepared thin, cylindrical noncutting flexible nickel-titanium (Ni-Ti) wire (ϕ 0.26 mm, Fig. 2). The Ni-Ti wire used was a shaft of a Lightspeed instrument whose cutting head had been removed. The shaft itself was not further modified except for polishing the cut surface using 1000 grit polishing discs. All ultrasonic tips were placed 1 mm short of the working lengths and no attempt was made to shape the canals with these ultrasonic tips. A final flush with NaOCl concluded the preparation in these groups. Ultrasonic energy was delivered by a standard unit (Piezon

Table 1 Experimental protocol listing both negative controls and the four test groups. Details of preparation techniques, irrigants used with or without ultrasonics, and the types of ultrasonic tips tested are also given

Groups	Apical size	Irrigant	Ultrasonics
1 ProFile .04 Control	# 45	NaOCl/EDTA	-
2 ProFile .04 + Ultrasonic [File]	# 45	NaOCl/EDTA	+
3 ProFile .04 + Ultrasonic [Wire]	# 45	NaOCl/EDTA	+
4 Lightspeed Control	# 45	NaOCl/EDTA	-
5 Lightspeed + Ultrasonic [File]	# 45	NaOCl/EDTA	+
6 Lightspeed + Ultrasonic [Wire]	# 45	NaOCl/EDTA	+

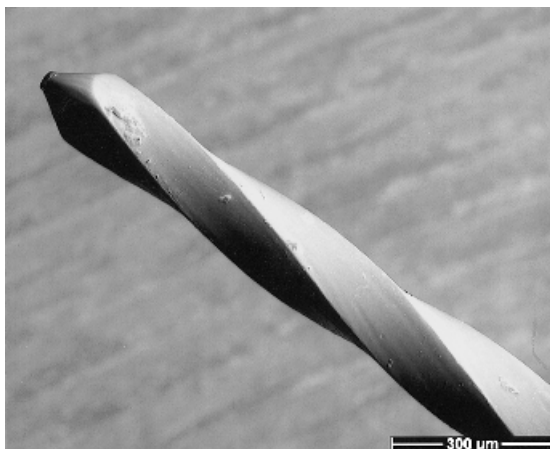


Figure 1 SEM micrograph of a size 15 stainless steel K-file used for ultrasonic activation of the irrigation in groups 2 and 5 (original magnification 150×).

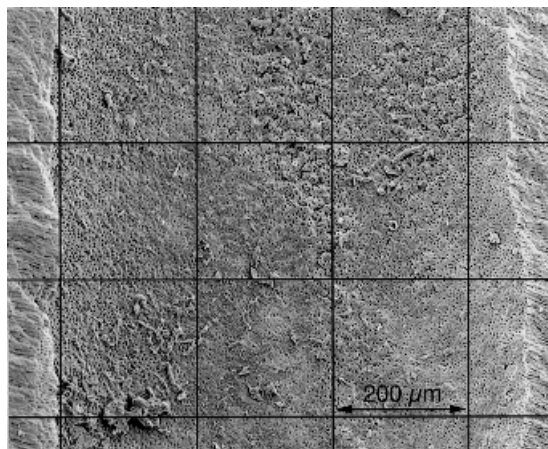


Figure 3 SEM micrograph of the 200 μm square grid used to score smear layer and debris (original magnification 200×).

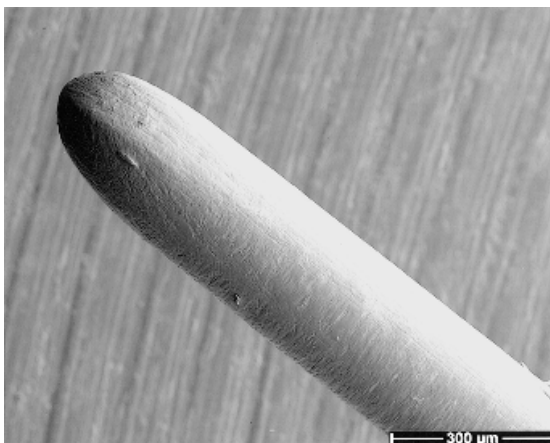


Figure 2 SEM micrograph of a blunt Ni-Ti-wire, diameter 0.26 mm, used for ultrasonic activation of the irrigation in groups 3 and 6 (original magnification 150×).

Master 400, EMS, Nyon, Switzerland). Power settings were established in pilot experiments so that the outer surface root temperature did not exceed 40 °C.

From this point on, all specimens were treated similarly, dried with paper points and temporized with Cavit (Espe, Seefeld, Germany). Root surfaces were grooved to indicate levels 3, 6, and 9 mm from the root apices using separation disks (Intensiv, Bioggio, Switzerland) and the specimens were decoronated. Specimens were immersed in liquid nitrogen and split longitudinally in the buccolingual plane, taking care not to contaminate the canals with debris. Canal halves were secured on metal stubs,

desiccated and sputter-coated with gold (500 A°, Balzers CSD 030, Balzers, Liechtenstein). Specimens were examined in a SEM (Cambridge Stereoscan 180, Cambridge, UK) at low power (15×) and serial photomicrographs were taken of the canal walls at 200× and 400× magnification at the 3-, 6-, and 9 mm levels. These serial photographs were placed adjacent to each other, forming a continuous horizontal examination strip at the three levels. A 200- μm square grid was superimposed onto the strip (Fig. 3), from which the debris and smear layer scores were evaluated. The number of 'assessment units' varied from 6 to 91, depending on root canal diameters, whereas the height of the examination strips was set at 600 μm . Specimens were evaluated for incidence of scratched canal surfaces at low and high power.

Amounts of smear layer and debris present in each of the 'assessment units' were assessed using a 5-step scale and recorded. The amounts of smear layer present at 200× magnification were graded between 1 and 5. A score of 1 was assigned when all dentinal tubules were open, and no smear layer was present or if uninstrumented calcospherites were noted. A score of 2 was recorded when some dentinal tubules were open and others covered by a thin smear layer. A score of 3 was recorded when a few tubules were open and the rest covered by a thin homogenous smear layer. A score of 4 was recorded when all dentinal tubules were covered by a homogenous smear layer without any open tubules visible. A score of 5 was recorded when a thick homogenous smear layer completely covered the canal walls.

The amounts of debris present at 200× magnification were graded between 1 and 5. A score of 1 was assigned when no debris or only isolated small particles were present. A score of 2 was recorded when minimal debris particles were present in small clumps. A score of 3 was recorded when clumps of debris particles covered less than 50% of the canal wall. A score of 4 was recorded when clumps of debris particles covered more than 50% of the canal wall. A score of 5 was recorded when clumps of debris particles completely covered the canal wall.

For each evaluation strip, average scores for smear layer and debris were calculated from the raw data by dividing the sum of all individual scores by the number of assessment units. Means recorded at the 3, 6 and 9 mm examination levels were statistically analysed for significance ($\alpha < 0.05$) between and within the groups using the Mann–Whitney *U*-test and the Kruskal–Wallis test.

Results

Mean amounts of smear layer and debris recorded at the 3 mm, 6 mm and 9 mm levels in the four test and two control groups are listed in Tables 2 and 3. Of a possible maximum of 5, mean smear layer scores in all six groups at the three levels evaluated ranged from

1.85 ± 0.61 to 3.67 ± 0.84 (Table 2). Significantly higher ($P < 0.05$) smear layer scores were found at the 3 mm compared to the 9 mm levels in all groups. Between the three ProFile groups (Groups 1–3), no significant differences in smear layer scores were recorded at the three levels examined (Table 2). Similarly, no significant differences in smear layer scores were recorded at the three levels examined between the Lightspeed control group and the two Lightspeed test groups (groups 4–6).

Of a possible maximum of 5, mean debris scores in all six groups at the three levels evaluated ranged from 1.30 ± 0.38 to 2.48 ± 0.95 (Table 3). As for smear layer scores, significantly higher ($P < 0.05$) debris scores were found at the 3 mm compared to the 9 mm levels in all groups. However, there were no differences in the means at the three levels evaluated between the six groups.

Between the three ProFile groups, no significant differences in debris scores were recorded at the three levels (Table 3). Similarly, no significant differences in smear layer scores were recorded at the three levels examined between the Lightspeed control group and the two Lightspeed test groups. On the basis of these findings, there were no differences in the amounts of smear layer and debris on canal wall prepared with ProFile or Lightspeed instruments.

Table 2 Mean smear layer scores (\pm SD) for the six groups at 3 mm, 6 mm and 9 mm levels

Group	3 mm	6 mm	9 mm
1 ProFile .04 Control	$3.67 \pm 0.84^*$	3.36 ± 1.22	$2.55 \pm 1.19^*$
2 ProFile .04 \pm Ultrasonic [File]	$2.75 \pm 0.93^*$	2.53 ± 1.22	$2.08 \pm 1.11^*$
3 ProFile .04 \pm Ultrasonic [Wire]	$3.24 \pm 0.76^*$	1.85 ± 0.61	$2.59 \pm 0.87^*$
4 Lightspeed Control	$3.29 \pm 1.10^*$	3.24 ± 0.91	$1.88 \pm 0.94^*$
5 Lightspeed \pm Ultrasonic [File]	$2.89 \pm 1.10^*$	2.20 ± 1.14	$2.01 \pm 0.92^*$
6 Lightspeed \pm Ultrasonic [Wire]	$3.13 \pm 1.17^*$	2.72 ± 0.89	$1.86 \pm 0.97^*$

* $P < 0.05$.

Significantly different scores within groups are indicated.

Table 3 Mean debris scores (\pm SD) for the six groups at 3 mm, 6 mm and 9 mm levels

Group	3 mm	6 mm	9 mm
1 ProFile .04 Control	$2.17 \pm 1.06^*$	1.99 ± 0.84	$1.42 \pm 0.42^*$
2 ProFile .04 \pm Ultrasonic [File]	$1.83 \pm 0.54^*$	1.67 ± 0.72	$1.41 \pm 0.24^*$
3 ProFile .04 \pm Ultrasonic [Wire]	$2.19 \pm 1.08^*$	1.85 ± 0.61	$1.59 \pm 0.58^*$
4 Lightspeed Control	$1.84 \pm 0.75^*$	1.65 ± 0.38	$1.30 \pm 0.38^*$
5 Lightspeed \pm Ultrasonic [File]	$2.26 \pm 1.04^*$	1.78 ± 0.59	$1.53 \pm 0.43^*$
6 Lightspeed \pm Ultrasonic [Wire]	$2.48 \pm 0.90^*$	1.94 ± 0.71	$1.74 \pm 0.53^*$

* $P < 0.05$.

Significantly different scores within groups are indicated.

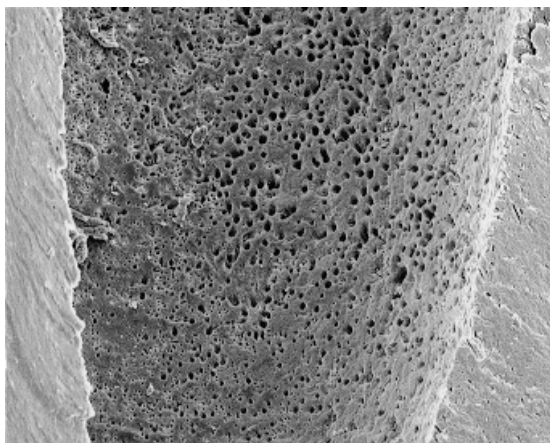


Figure 4 SEM micrograph of an apical area prepared by Lightspeed and the irrigant then activated using a size 15 stainless steel K-file. Small amounts of debris and complete removal of smear layer is visible (original magnification 400×).

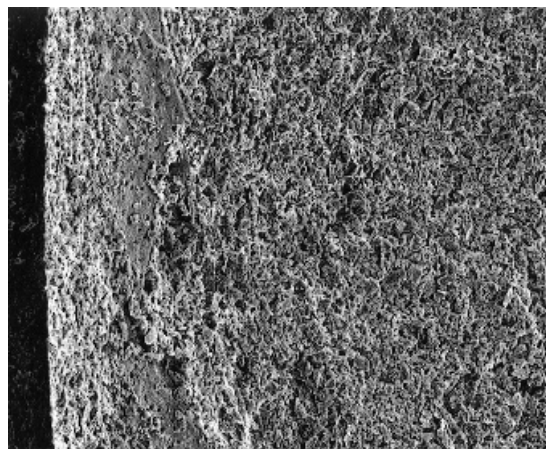


Figure 6 SEM micrograph of an apical area prepared by Lightspeed and the irrigant then activated using a blunt Ni-Ti-wire with a diameter of 0.26 mm. The canal wall is almost completely covered with debris (original magnification 200×).



Figure 5 SEM micrograph of an apical area prepared by ProFile .04 and the irrigant then activated using a size 15 stainless steel K-file. Large amounts of debris and smear layer were present (original magnification 400×).

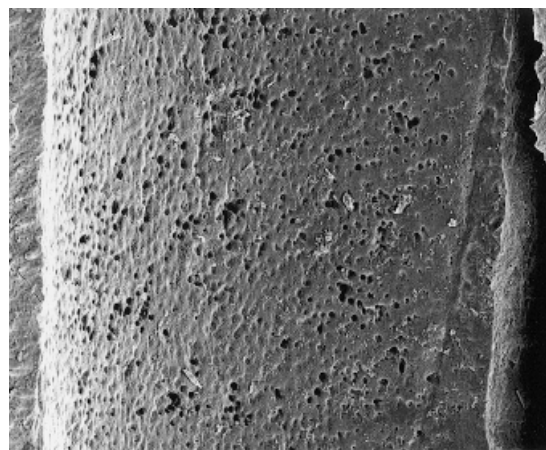


Figure 7 SEM micrograph of an apical area prepared by ProFile .04 and the irrigant then activated using a blunt Ni-Ti-wire with a diameter of 0.26 mm. The canal wall is free of debris. Many dentine tubules are open, while the remainder are covered by a thin smear layer (original magnification 200×).

The effects of ultrasonic energy are studied by grouping all canals together regardless of the rotary technique used. Smear layer and debris scores produced by the stainless steel files (Figs 4, 5) and by the blunt nickel-titanium wires (Figs 6, 7) were then compared to that produced by the two negative control groups (Fig. 8). Overall, significantly higher mean debris scores were recorded at the 3 mm level compared to the 9 mm level for the K-file group, the control group and the Ni-Ti-wire group (Fig. 8). Furthermore, there

were significantly higher mean debris scores at the 6 mm level compared to the 3 mm level in the control group.

Significantly higher mean smear layer scores were recorded at the 3 mm level compared to the 9 mm level for the control group and the Ni-Ti-wire group. In addition, significantly higher mean smear layer scores were noted at the 6 mm level compared to the 3 mm level in the control group and the Ni-Ti-wire group (Fig. 8).

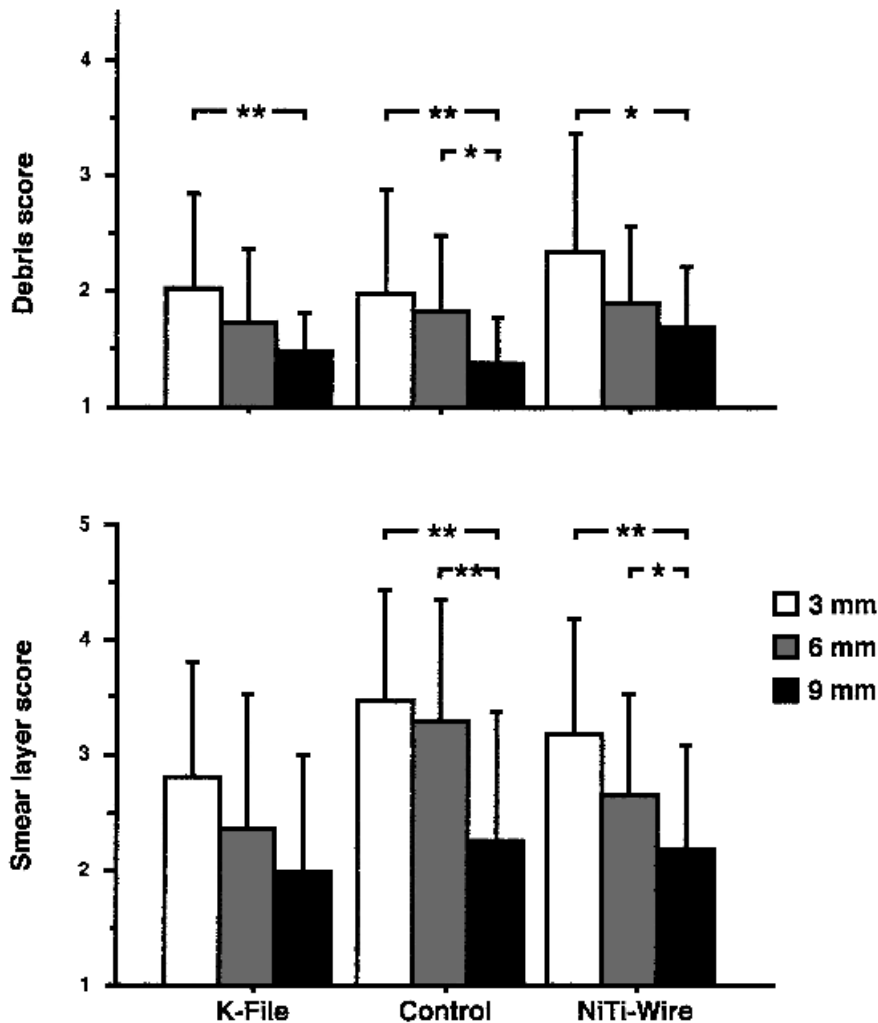


Figure 8 Bar diagrams showing both mean debris and smear layer scores (\pm SD) at 3 mm, 6 mm and 9 mm levels for canals ultrasonicated using K-files, Ni-Ti-wire or without ultrasonic energy (control). Significant differences are indicated as ★ $P < 0.05$ or as ★★ $P < 0.01$.

Discussion

The aim of this study was to test for differences between two rotary canal preparation techniques and the role of ultrasonic activated irrigation on the cleanliness of root canal walls. Two tips of different design and material, a cutting stainless steel K-file and a blunt Ni-Ti-wire, were compared as transmitters of ultrasonic energy to activate irrigants. Because of their cutting surfaces, fluted stainless-steel files were expected to produce more debris and smear layer than the smooth-surfaced Ni-Ti flexible wire.

Varying methods have been described in previous studies evaluating the effects of ultrasonics on canal wall

cleanliness. Therefore, methodology should be initially considered before comparing results.

Canal size and instrument diameter

The diameter of the canal determines the amplitude of the oscillating instrument tip. With this in mind, Cunningham & Martin (1982) used ultrasonic files for preparation but no definitive canal size was achieved. In contrast, Jensen *et al.* (1999) prepared canals up to size 55. These two studies, plus that by Goodman *et al.* (1985) showed improved root canal debridement, particularly in the middle and coronal thirds of canals. The oscillation of the tips of ultrasonic instruments is decreased by

constraining it in the root canal. Because the amplitude of the oscillation is largest at the instrument's tip, any attenuation affects the apical part most significantly (Walmsley & Williams 1989), where the diameter of the canal is smallest. The current results confirm that the apical part of the canals was least influenced by the activated irrigation.

The size 15 K-File used in groups 2 and 5 had a .02 taper with a diameter corresponding to a size 47 file at the point where the cutting flutes terminated. In contrast, the Ni-Ti-wire used was cylindrical and 0.26 in diameter. In narrow canals larger instruments have limited space to oscillate freely and may consequently be less efficient than similar instruments with a smaller diameter. The larger diameter of the Ni-Ti-wire in the apical part may have produced significantly higher mean smear layer scores at the 3 mm level compared to the 9 mm and the 6 mm levels.

Cavitation and acoustic streaming are considered important physical phenomena influencing canal debridement when using ultrasonic devices (Ahmad *et al.* 1987). Ultrasonically activated files produced streaming patterns close to the file, continuously moving irrigants around, thereby producing shear stresses, which could damage biological cells and remove debris (Ahmad 1989). Of the two procedures, acoustic streaming is considered more relevant than cavitation (Ahmad *et al.* 1987). These facts may explain the finding, that there was significantly more debris found at the 3 mm levels of both the K-File and Ni-Ti-wire groups compared to the 9 mm levels.

Volume of irrigant

Another important factor is the volume of the irrigation. Previous studies have shown that the volume of irrigant influenced the cleanliness of the root canal. Larger volumes of NaOCl and EDTA yielded significantly cleaner canal walls than smaller volumes (Yamada 1983). For the current study, a continuous irrigation supply was not chosen so that the volume of irrigant was the same for both the two control and four test groups. Some ultrasonic units, such as the Piezon Master, can supply a continuous flow of irrigant. This produces a high volume irrigation of up to 20 mL min⁻¹ and its effect can not be compared to the volume (2 mL of NaOCl or 2 mL of EDTA) delivered by a 27-gauge needle.

Cameron (1995) reported that the most effective regime with ultrasonic energy was to activate each and every dose of irrigant placed in the canal. In that study, the time required for irrigation was roughly 18 min per

canal. In the current study, irrigating times of 1 min each for EDTA and NaOCl was selected after canal preparation, as this seems clinically practical. Consequently, the active irrigation time in the control and test groups was similar in the current study. Under these conditions, the use of ultrasonic energy for irrigant activation did not improve debridement compared to the control groups.

However, this finding is in contrast to previous studies (Cunningham & Martin 1982, Cameron 1995, Jensen *et al.* 1999). To highlight just how ultrasonic methods vary, a light microscopic study by Jensen *et al.* (1999) activated the irrigant after preparation, 2 mm short of working length, for 3 min; this enabled the ultrasonic instrument tip to oscillate more freely in the canal.

Scoring methods

A variety of procedures have been described to score the amounts of debris and smear layer left on canal walls after instrumentation. Some studies used only one score at each level examined (Hülsmann *et al.* 1997, Peters & Barbakow 2000). However, in the current study, a 200- μ m square grid was superimposed over the photomicrographs and the amounts of debris and smear layer were evaluated in each assessment unit. However, a grid scoring method may be more accurate to score debris and smear layer because they are often non-uniformly distributed. Consequently, one could speculate that the grid method would yield more accurate findings than a single score per level examined (Wu & Wesselink 1995).

Of the two alloys tested in the current study, the stainless steel K-files used to transmit the ultrasonic energy yielded a more scratched surface than the flexible blunt Ni-Ti-wire. Two specimens ultrasonicated with the flexible blunt Ni-Ti-wire had defects compared to 12 specimens ultrasonicated using the stainless steel K-files. Despite the greater incidence of defects in the stainless steel groups, their canal walls were not significantly cleaner than the walls in the blunt Ni-Ti groups. Any possible antibacterial effects dependent upon the ultrasonic energy transmitted by the two alloys were not investigated. However, previous studies have shown improved antibacterial activity of NaOCl (Briseno *et al.* 1992), when used with ultrasonics. The antibacterial potential of ultrasonically activated irrigation may play an important role and should be investigated in future.

The clinical relevance of the current study indicated that activated irrigation did not significantly reduce smear layer and debris scores when using stainless steel K-files and Ni-Ti-wire as ultrasonic transmitters. However, antibacterial effects of the ultrasonically activated

irrigants, transmitted with either Ni–Ti-wire or stainless steel K-files, may be more efficient when used with an ultrasonic unit compared to a disposable syringe and needle.

Conclusions

Under the conditions of this study, ultrasonically activated irrigation did not reduce debris nor smear layer scores of prepared root canals. This finding was not influenced by the design of nor the material used to fabricate the ultrasonic tips used to transmit ultrasonic energy. No significant differences in cleaning root canals were recorded between the Lightspeed and ProFile .04 rotary instruments evaluated.

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