The effect of high-frequency electrical pulses on organic tissue in root canals

M. Lendini[2], E. Alemanno[2], G. Migliaretti[3] & E. Berutti[1]

[1]Department of Endodontics, School of Dentistry, Turin University, Turin, Italy; [2]Private Practitioner, Turin, Italy; and [3]Department of Public Health and Microbiology, Turin University, Turin, Italy

Abstract

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Aims To evaluate debris and smear layer scores after application of high-frequency electrical pulses produced by the Endox Endodontic System (Lysis Srl, Nova Milanese, Italy) on intact pulp tissue and organic and inorganic residues after endodontic instrumentation.

Methodology The study comprised 75 teeth planned for extraction. The teeth were randomly divided into two groups (60 teeth) and a control group (15 teeth): group 1 (30 teeth) was not subjected to instrumentation; group 2 (30 teeth) was instrumented by Hero Shaper instruments and apical stops were prepared to size 40. Each group was subdivided into subgroups A and B (15 teeth); two electrical pulses were applied to subgroups 1A and 2A (one in the apical third and one in the middle third, respectively, at 3 and 6 mm from the root apices); four electrical pulses were applied to subgroups 1B and 2B (two in the apical third, two in the middle third). The control group (15 teeth) was prepared with Hero Shapers and irrigated with 5 mL of EDTA (10%) and 5 mL of 5% NaOCl at 50 °C but not subjected to the electrical pulse treatment. Roots were split longitudinally and canal walls were examined at 80×, 200×, 750×, 1500× and 15 000× magnifications, using a scanning electron microscope. Smear layer and debris scores were recorded at the 3 and 6 mm levels using a five-step scoring scale and a 200-μm grid. Means were tested for significance using the one-way ANOVA model and the Bonferroni *post-hoc* test. The differences between groups were considered to be statistically significant when $P < 0.05$.

Results The mean value for debris scores for the three groups varied from 1.80 (±0.77) to 4.50 (±0.68). The smear layer scores for group 2 and the control specimens varied from 2.00 (±0.91) to 2.33 (±0.99). A significant difference was found in mean debris scores at the 3 and 6 mm levels between the three groups ($P < 0.001$). The Bonferroni *post-hoc* test confirmed that the difference was due to group 1. In the two subgroups treated with four high-frequency pulses (1B and 2B) a substantial reduction in mean debris scores was found at the 3 and 6 mm level; subgroup 2B was practically free of organic residue. No significant differences for mean smear layer and debris scores were recorded between group 2 and the control group at the two levels; a significant difference was found only for mean smear layer scores at the 3 mm level between subgroup 2B and the control group ($P < 0.05$).

Conclusions The Endox device used with four electrical pulses had optimal efficacy when used after mechanical instrumentation. Traditional canal shaping and cleaning was essential to ensure an effective use of high-frequency electrical pulses in eliminating residues of pulp tissue and inorganic debris.

Keywords: canal cleaning, high-frequency electrical pulses, irrigants.

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Introduction

The principal goal of root canal treatment is to clean and disinfect the root canal system, including those regions where access is difficult, such as canal irregu-

Correspondence: Mario Lendini, Via Felice Romani 27, 10131 Torino, Italy (Tel.: +39011/8196989; fax: +39011/8197717; e-mail: mario@drlendini.it).

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larities and the openings of dentinal tubules. The chemical removal of infected pulp tissue and disinfection of dentine surfaces with irrigants is of particular importance. Furthermore if the canal is not clean, it cannot be filled properly as the remaining tissue will prevent adaptation of the sealer (Wu *et al.* 2002, Ardila *et al.* 2003).

Shaping the canal both manually and mechanically, opens the complex pulp space to the action of irrigants. Sodium hypochlorite (NaOCl) is still the most widely used irrigant and meets many of the ideal requirements; however, it needs adequate contact time to achieve optimal bactericidal and pulp-solvent action. NaOCl acts by releasing chlorine, which has bactericidal properties (Berutti *et al.* 1997). Data reported in the literature suggested that 2% NaOCl *in vitro* at 37 °C dissolves 15% of human pulp within 15 min; at 1 h this rises to 50%, and increases to 100% after 2 h (Andersen *et al.* 1992). It has also been reported that the same irrigant at concentrations ranging between 1 and 5.25% has bactericidal capability (Penick & Osetek 1970, Abou-Rass 1982) and can dissolve organic tissues (Yamada *et al.* 1983, Baumgartner & Mader 1987), whereas it is unable to remove the smear layer (Prati *et al.* 1994, Berutti 1999). NaOCl becomes toxic at concentrations above 5.5% (Harrison *et al.* 1978, Brown *et al.* 1995, Mehra *et al.* 2000). The solvent action is increased on raising the temperature, but this does not alter the bactericidal capability (Cunningham & Joseph 1980). In order to remove the smear layer produced by instrumentation, NaOCl must be associated with other chelating agents such as EDTA at 10–17%, or citric, phosphoric or tannic acids (Baumgartner & Mader 1987, Berutti *et al.* 1997). However, recent studies have shown that the combination of NaOCl and EDTA cannot always completely remove the smear layer and pulp debris (Ciucchi *et al.* 1989, Takeda *et al.* 1999).

Rotary nickel-titanium instruments represent a revolutionary step forward in root canal preparation techniques. However, in some cases reduction of operative time has a negative impact on the action of canal irrigants. Where there is necrotic tissue or fixed tissue, contact time between canal irrigants and organic material in the canal system must be sufficient (Abou-Rass & Oglesby 1981). Thus, supplementary systems may be needed to obtain a more complete debridement of the canal system.

The Endox Endodontic System (Fig. 1) exploits high-frequency electrical pulses (high-frequency electric waves) to eliminate organic tissue within the root

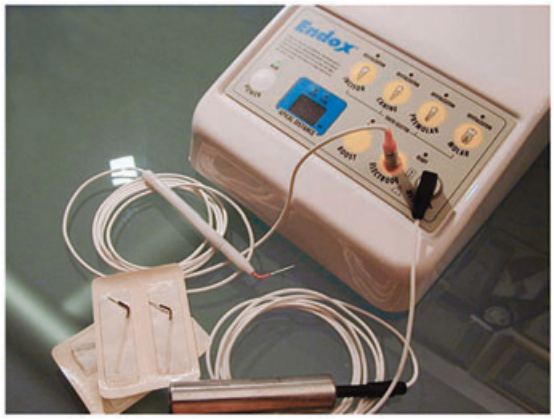

Figure 1 Endox Endodontic System.

canal. All tissues possess a molecular structure that is sensitive to the action produced by electromagnetic fields generated by a high-frequency current. The flow of electrons generates a packet of electromagnetic waves that releases a considerable quantity of energy in the field involved by the electrical discharge and in immediately surrounding areas. There are three main effects: increase of local temperature (between 300 and 500 °C), increased percentage of ozone (O_3) due to ionization of the medium, and production of UV rays. The latter are a by-product of the spark generated by the flow of electrons in the medium. These effects are assumed to act synergistically, eliminating the content of the root canal by vaporizing all organic and inorganic components.

The device possesses a series of precalibrated operating conditions that make it possible to apply a preset discharge dependent on the volume and mass of the tooth to be treated. From the clinical standpoint, the number of pulses used may be varied depending on the volume of the canal system. The high-frequency electrical pulses are emitted through a probe that conducts the electrical pulse, and which is available in different diameters (Fig. 2).

The Endox Endodontic System is also provided with an electronic apex measuring device regulated such that 'zero' in reality corresponds to 1 mm from the foramen. The safety of the device is enhanced by an automatic device that inhibits pulse emission at that point and beyond.

The aim of this study was to determine the effects of different doses of high-frequency electrical pulses on intact pulp tissue and on organic and inorganic residues remaining after endodontic instrumentation. At present, the Endox Endodontic System (Lysis Srl,

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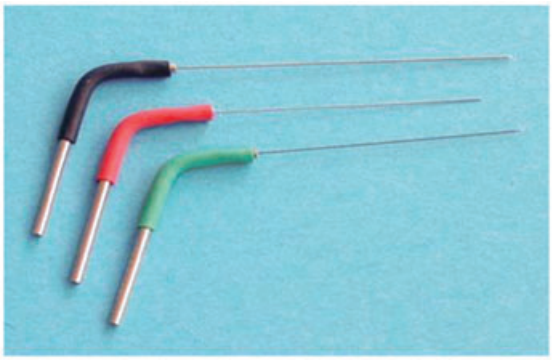

Figure 2 Different tips, suitable for different clinical utilization, can be mounted on to the hand-piece of the Endox Endodontic System.

Nova Milanese, Italy) is the only instrument available that exploits this technology (Haffner *et al.* 1999).

Materials and methods

The selection criteria included patients in good health, not wearing pacemaker devices, aged between 30 and 50 years and affected by periodontal disease. Single-rooted premolars and canines were included according to the following selection criteria:

- Mean length 25 ± 2 mm – from the top of the buccal cusp to the apex – measured on radiographs obtained with a paralleling technique.
- The periodontal condition and high mobility indicated a need for extraction: degree 3 of tooth mobility measured according to Lindhe *et al.* (1997).

Each patient was instructed on the therapeutic procedures required and consent obtained that included approval for the endodontic therapy, radiographs to confirm the working length and for the use of electrical high-frequency pulses in the canal prior to tooth extraction.

The Endox Endodontic System was applied *in vivo* to 60 single-rooted premolar and canine teeth, each with a single root canal. The frequency used to obtain the pulse was that set by the Endox Endodontic System for a tooth with root-system volume comparable with that of a canine and premolar, that is 312.5 kHz. The discharge voltage was approximately 1100 V with an application time of 0.14 s. This effect may be obtained because the electrical resistance of the endodontic environment is only between 6000 and 8000 Ω, whereas that of the human body is on average 600,000 Ω.

Subjects were divided at random into two equal groups, group 1 and group 2. Each group was further randomly subdivided into two subgroups, A and B. The following operative protocols were applied:

Teeth in group 1 were isolated with a rubber dam, the surfaces were cleaned with a chlorhexidine solution, followed by Corsodyl gel (GlaxoSmithKline, Verona, Italy) for 60 s. The pulp chamber was then opened using a high-speed cylindrical diamond bur (Komet 010, Lemgo, Germany) and pulpotomy was performed by a low-speed Müller bur (Komet). An apex locator, Elements Diagnostic (SybronEndo, Glendora, CA, USA), was used to measure the canal root length. No canal instrumentation of any type was performed. High-frequency electrical pulses were applied *in vivo* (Endox Endodontic System and red needle: length 24 mm, diameter 0.12 mm, AM2400) at 3 and 6 mm level from the root apices, in the apical and middle third of each root canal. The apical and middle thirds were included in evaluation tests, because they are the most difficult endodontic areas to be cleaned (Baumgartner & Mader 1987). The pulses were applied as follows:

Subgroup 1A (15 subjects):

- one pulse in the middle third (at 6 mm level)
- one pulse in the apical third (at 3 mm level)

Subgroup 1B (15 subjects):

- two pulses in the middle third (at 6 mm level)
- two pulses in the apical third (at 3 mm level)

Teeth in group 2 were treated in the same way following mechanical endodontic instrumentation using rotary nickel-titanium instruments. Hero Shaper instruments (Micro-Mega, Besançon Cedex, France), 25 mm in length were used in the following sequence: size 25, 6% taper; size 25, 4% taper; size 30, 4% taper.

An apex locator, Elements Diagnostic (SybronEndo), was used to measure the canal root length. All root canals were prepared up to size 40 at the working length. The only irrigant used was 10 mL of physiological saline solution by a plastic syringe with a closed-end needle (Vista-Probe Irrigating Needle Tips - 25ga. Vista Dental Products, Racine, WI, USA). No other physical or chemical treatment was used to restrict the removal of intracanal organic tissue exclusively to the instrument's mechanical action. The choice of this method is determined by the need to evaluate the action of different doses of high-frequency electrical pulses on organic and inorganic residues remaining after endodontic instrumentation. High-frequency electrical pulses were then applied *in vivo* (Endox Endodontic System; red needle) as follows:

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Subgroup 2B (15 subjects):
- one pulse in the middle third (at 6 mm level)
- one pulse in the apical third (at 3 mm level)

Subgroup 2A (15 subjects):
- two pulses in the middle third (at 6 mm level)
- two pulses in the apical third (at 3 mm level)

Teeth in control group (15 subjects) were treated as in group 2, with mechanical nickel-titanium endodontic instrumentation, using Hero Shaper instruments and chemical irrigants, but were not subjected to pulse treatment. All canals were irrigated with 5 mL of 5% NaOCl solution (at 50 °C) and 5 mL of 10% EDTA, alternatively, after each instrument. A final flush with NaOCl concluded the preparation.

In all subjects canals were dried with paper points (Inline-B.M. Dentale, Torino, Italy) and the access cavity was then sealed with a sterile cotton pellet and composite material. The tooth was immediately extracted and fixed (phosphate buffer at pH 7.2 with 4% formaldehyde). Root surfaces were grooved to indicate levels 3 and 6 mm (respectively, apical and middle third) from the root apices using separation disks (Intensiv, Boggio, Switzerland). Specimens were decoronated and split longitudinally and immersed in serial solutions of water and ethanol as follows: 75% water/25% ethanol; 50/50; 25/75; and finally 100% ethanol. Specimens were left in each bath for 72 h. They were then treated with hexamethyldisilazane to obtain the necessary degree of dehydration, and gold-coated with an Agar Auto Sputter Coater for observation under an SEM, LEO 420 (LEO Electron Microscopy Ltd, Cambridge, UK).

Specimens were observed under the SEM at the 3 and 6 mm levels under magnifications ranging from ×80 to ×15 000, by an independent observer who was unaware of the specific treatment protocol of each specimen. Separate evaluations were undertaken for debris and smear layer for each group. Group 1, not subjected to mechanical instrumentation, was evaluated only for debris, and not for smear layer. According to the glossary of the American Association of Endodontists (1994), smear layer is defined as a surface film of debris retained on dentine or other surfaces after instrumentation with either rotary instruments or endodontic files (Hülsmann *et al.* 1997). In order to compare specimens of all groups, the apical and median areas of the root canal were analysed at ×200 magnification superimposing a reference 200 μm square grid onto the strip (Fig. 3), from which debris and smear layer scores were evaluated. Amounts of smear layer and debris present in each of the 'assessment units' were assessed using a five-step scale and recorded according to Hülsmann *et al.* (1997) (see Tables 1 and 2). 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.

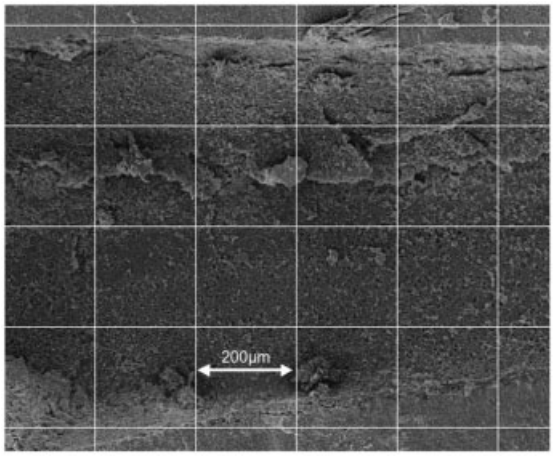

Figure 3 SEM micrograph of the 200 μm square grid used to score smear layer and debris (original magnification 200×).

The goal was to determine the effect of high-frequency electrical pulses alone or combined with instrumentation, applied at different doses to specimens that had not been subjected to aggressive chemical

Table 1 Scoring criteria for cleanliness

Score	Debris
1	Clean root canal wall, only few small debris particles
2	Few small agglomerations of debris
3	Many agglomerations of debris, covering <50% of the canal wall
4	More than 50% of the canal wall covered by debris
5	Complete or nearly complete root canal wall completely covered by debris

Table 2 Scoring criteria for patency

Score	Smear layer
1	No smear layer, dentinal tubuli open
2	Small amount of smear layer, some dentinal tubuli open
3	Homogenous smear layer covering the root canal wall, only few dentinal tubuli open
4	Complete root canal wall covered by a homogenous smear layer, no dentinal tubuli open
5	Heavy, nonhomogenous smear layer covering the complete root canal wall

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irrigants. Moreover the purpose was to compare the two groups, subjected to pulses, with the control group, subjected to traditional endodontic technique, with chemical irrigants.

Statistical analysis

The score areas at 3 and 6 mm levels were expressed as mean and standard deviations for each group and for each subgroup. Each mean was shown with relative 95% confidence interval (95% CI). The score areas were compared amongst groups using the one-way ANOVA model and the Bonferroni *post-hoc* test. The differences between groups were considered to be statistically significant when $P < 0.05$. In the Bonferroni *post-hoc* test the significance level was corrected by the number of comparisons.

Results

Mean amounts of smear layer and debris, recorded at 3 and 6 mm levels in the two experimental groups and the control group are detailed in Table 3.

Table 3 Statistical analysis of the scores in the two groups and control group

Score level (mm)	Group 1	Group 2	Control	P[a]
Debris score (3 mm)				
Mean	3.87[b]	1.93	1.93	<0.001
SD	0.97	0.83	0.96	
95% CI				
Inf	3.52	1.64	1.45	
Sup	4.21	2.23	2.42	
Debris score (6 mm)				
Mean	4.50[b]	2.13	1.80	<0.001
SD	0.68	0.90	0.77	
95% CI				
Inf	4.26	1.81	1.41	
Sup	4.74	2.46	2.19	
Smear layer score (3 mm)				
Mean		2.00	2.33	<0.001
SD		0.91	0.90	
95% CI				
Inf		1.67	1.88	
Sup		2.33	2.79	
Smear layer score (6 mm)				
Mean		2.33	2.15	<0.001
SD		0.99	0.92	
95% CI				
Inf		1.98	1.69	
Sup		2.69	2.62	

[a]One-way ANOVA test.
[b]$P < 0.05$ when compared with the other two groups (group 2, control) separately (by Bonferroni *post-hoc* test).

Mean debris scores in all three groups at the two levels evaluated ranged from 1.80 (±0.77) to 4.50 (±0.68). Mean smear layer scores evaluated ranged from 2.00 (±0.91) to 2.33 (±0.99) (Table 3).

Microscopic observation showed that group 1 specimens (not subjected to mechanical instrumentation), treated with two or four high-frequency pulses, had canal walls that were completely or almost completely covered with debris (score values 4 and 5), specifically 27 of 30, at 6 mm level and 23 of 30 at 3 mm level (Fig. 4).

According to the one-way ANOVA model, a significant difference in mean debris scores occurred at 3 and 6 mm levels between the three groups. At the 3 mm level: group 1: mean 3.87, ±0.97; group 2: mean 1.93, ±0.83; control: mean 1.93, ±0.96 ($P < 0.001$; Table 3). At the 6 mm level: group 1: mean 4.5, ±0.68; group 2: mean 2.13, ±0.90; control: mean 1.80, ±0.77 ($P < 0.001$; Table 3). The Bonferroni *post-hoc* test showed that the difference was due to group 1 ($P < 0.05$; Table 3). The mean values for debris scores at the 3 mm level was different between the two subgroups 1A and 2A, 4.40 (95% CI: 4.03–4.77) and 2.53 (95% CI: 2.27–2.79), respectively ($P < 0.001$). Also at 6 mm level the two groups showed a significant difference between the means, 4.80 (95% CI: 4.59–5.01) and 2.73 (95% CI: 2.43–3.03), respectively, for subgroup 1A and 2A ($P < 0.001$; Tables 4 and 5). Similarly, significant differences in mean debris scores were recorded between subgroup 1B and 2B (four electrical impulses) at the 3 and 6 mm levels ($P < 0.001$; Tables 4 and 5).

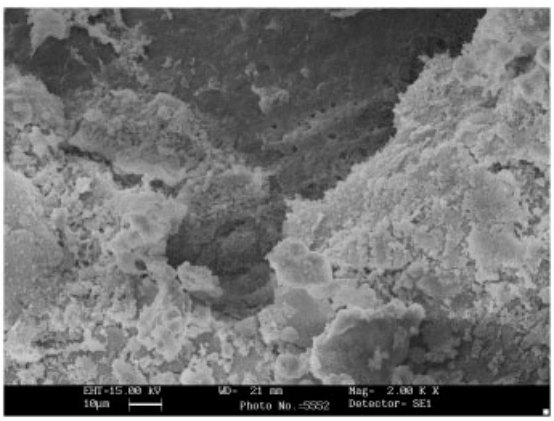

Figure 4 SEM image (2000×) of an area of the median third of a specimen in group 1, subgroup A (1 + 1 HF pulse). At 6 mm level, large clusters were partially detached from the canal wall. Score: 5.

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Table 4 Statistical analysis of debris scores in the two subgroups (A and B) of group 1

Score level (mm)	Subgroup 1A	Subgroup 1B	P^a
Debris score (3 mm)			
Mean	4.40	3.33	<0.01
SD	0.74	0.90	
95% CI			
Inf	4.03	2.88	
Sup	4.77	3.79	
Debris score (6 mm)			
Mean	4.80	4.20	0.01
SD	0.41	0.77	
95% CI			
Inf	4.59	3.81	
Sup	5.01	4.59	

[a]One-way ANOVA test.

Table 5 Statistical analysis of the scores in the two subgroups (A and B) of group 2

Score level (mm)	Subgroup 2A	Subgroup 2B	P^a
Debris score (3 mm)			
Mean	2.53	1.33	<0.01
SD	0.52	0.62	
95% CI			
Inf	2.27	1.02	
Sup	2.79	1.65	
Debris score (6 mm)			
Mean	2.73	1.53	<0.01
SD	0.59	0.74	
95% CI			
Inf	2.43	1.16	
Sup	3.03	1.91	
Smear layer score (3 mm)			
Mean	2.73	1.27	<0.01
SD	0.46	0.59	
95% CI			
Inf	2.50	0.97	
Sup	2.96	1.57	
Smear layer score (6 mm)			
Mean	3.00	1.67	<0.01
SD	0.65	0.82	
95% CI			
Inf	2.67	1.25	
Sup	3.33	2.08	

[a]One-way ANOVA test.

The level of cleanliness was better in group 2, subjected to mechanical instrumentation followed by high-frequency electrical pulses. Most specimens (21 of 30 with score values 1 and 2 for debris) in this group at the 3 mm level had canal walls virtually free of dentine debris and patent dentinal tubules. Eighteen of 30 specimens (score values 1 and 2 for smear layer) had a small amount of smear layer and some open dentinal tubules (Fig. 5).

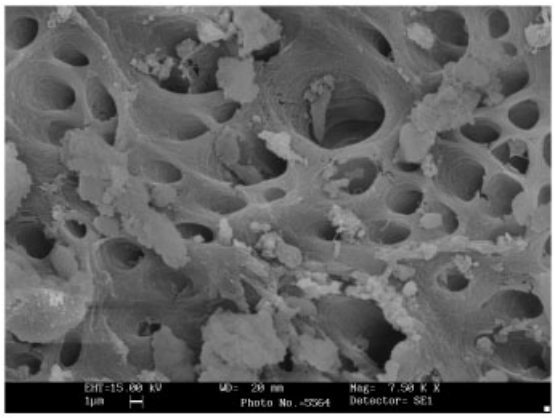

Figure 5 SEM image (7500×) of a surface in the median third of a specimen in group 2, subgroup B (2 + 2 HF electrical pulses). Most dentine tubules appear free and patent. Score 2.

Subgroups 1A and 1B were compared in terms of mean debris scores at the two levels. There was a marked difference in the degree of cleansing in the two subgroups, with a better result in subgroup 1B, particularly at the 3 mm level (Table 4). Similar results for debris and smear layer were observed between subgroup 2A and 2B at 3 mm level: a significant difference was observed between subgroup 2A and subgroup 2B ($P < 0.01$) (Table 5).

Significant differences in mean debris scores were found between subgroup 1B and the control group at the two levels. SEM observations showed interesting differences in the amounts of debris on canal walls prepared only with the Endox electrical device and canal walls subjected to mechanical instrumentation and chemical irrigation (control group): the latter being cleaner.

Between group 2 and the control group at the two levels no significant differences in mean debris scores were recorded. Finally, a significant difference in mean smear layer scores at the 3 mm level was recorded between subgroup 2B and the control group ($P < 0.05$).

Discussion

This study investigated the effects of two different doses of high-frequency electrical pulses applied to intact pulp tissue (group 1) and to organic and inorganic debris remaining after NiTi rotary endodontic instrumentation without any intra-canal chemical treatment (group 2). The two groups were also compared to a control group, subjected to mechanical instrumenta-

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tion and chemical irrigation with 5 mL of 5% NaOCl (at 50 °C) solution and 5 mL of 10% EDTA. The number of pulses was deliberately kept low (two pulses for specimens in subgroup A and four pulses for specimens in subgroup B) so as to observe the effects produced by a minimal number of pulses.

Measurements made *in vitro* have estimated that the increase in temperature, in the apical area reaches a maximum of 19 ± 4 °C following each electrical pulse, and that the mean cooling time was approximately 40 ± 6 s. This increase in temperature seems not to damage periradicular structures (Haffner *et al.* 1999). According to other studies a 10 °C rise sustained for 1 min is considered compatible with normal bone repair, but higher temperatures or longer application times may cause bone necrosis and its replacement with fatty tissue (Eriksson & Albrektsson 1983, Bailey *et al.* 2004). Endox pulses vaporize smear layer and organic tissue, including nerves, in the field involved by the electrical discharge and in immediately surrounding areas (Haffner *et al.* 1999). Clinical utilization of the system is contraindicated in patients wearing pacemaker devices. The canal should be carefully washed with physiological saline solution to avoid the vaporization processes producing apical extrusion of NaOCl, which would cause postoperative pain.

The efficacy of high-frequency electrical pulses has here been shown to be of interest, taking into account the fact that in group 2 the only canal irrigant used to complement mechanical nickel-titanium instrumentation was physiological saline solution. The high-frequency electrical pulses achieved satisfactory results on specimens subjected to four pulses after canal instrumentation. These data are in agreement with clinical observations: when specimens in group 2B were observed at high magnification (×7500) even dentine tubules of diameter above 12 μm were patent and completely free of organic residue (Fig. 6). The results reported, based on direct observation and on statistical analysis, indicate that the Endox instrument was effective only after canal instrumentation.

A significant difference in mean smear layer scores at the 3 mm level was recorded between subgroup 2B and the control group ($P < 0.05$), but this result should be analysed further using more subjects and including various additional clinical parameters.

These initial findings underline the importance of using conventional canal preparation in order to achieve a threshold level of cleanliness.

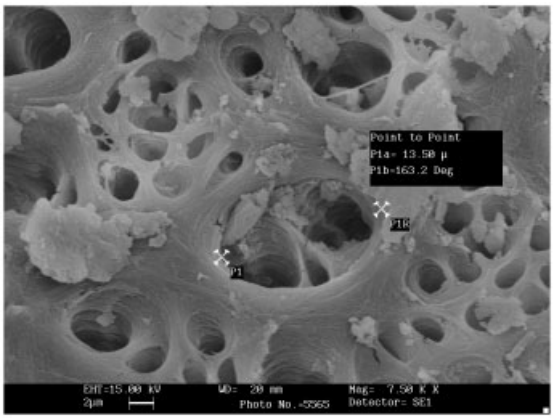

Figure 6 SEM image (7500×) of a surface in the apical third of a specimen in group 2, subgroup B (2 + 2 HF pulses). Even the larger dentine tubules appear patent. Score 1.

Conclusions

- Endox System does not provide satisfactory elimination of pulp tissue without mechanical endodontic instrumentation.
- At present high-frequency electrical pulses are not an effective system as sole endodontic treatment.
- At least four high-frequency pulses may be utilized as a supplement to traditional endodontic techniques to improve the cleansing and elimination of organic residues within the canal system, in teeth similar to the ones reported in the present study.

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