Effectiveness of oxidative potential water as a root canal irrigant

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Abstract

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Aim The aim of this study was to evaluate the effectiveness of oxidative potential water (OPW) as an irrigant, based on its ability to remove the smear layer and/or debris from instrumented root canals.

Methodology One hundred and twenty root canals from extracted human maxillary incisors were instrumented using a conventional step-back technique with irrigation from sodium hypochlorite (NaOCl) or oxidative potential water (OPW). After instrumentation, the canals were irrigated by syringe or ultrasound using 15% EDTA or OPW as an irrigant. The volume of each irrigant used for syringe irrigation was 10, 20, and 30 mL, respectively, whilst the duration for ultrasonic irrigation was 1, 3, and 5 min, respectively. After irrigation, each root was split longitudinally in two with cutting pliers, and the specimens were prepared for SEM observation. The presence of debris and smear layer on each canal wall was assessed using a three-point scale for each parameter.

Results Smear layer was effectively removed with EDTA both introduced via syringe and via ultrasonic irrigation. A similar effect was observed with OPW via syringe irrigation following instrumentation with 5% NaOCl. The canal walls in any of these cases showed open and patent dentinal tubules following smear layer removal. Some specimens irrigated with EDTA exhibited the effect of demineralization on the dentine resulting in funnelling of tubule orifices. Syringe irrigation was more effective in smear layer removal, except for ultrasonic irrigation with 15% EDTA, whilst ultrasonic irrigation was more effective in debris removal including the use of OPW as irrigant following instrumentation with 5% NaOCl. Neither syringe nor ultrasonic irrigation with OPW following instrumentation with OPW removed smear layer or debris effectively.

Conclusions The most effective irrigation technique for smear removal was 15% EDTA irrigation by means of syringe following instrumentation with 5% NaOCl solution. However, the most effective irrigation technique for debris removal was ultrasonic irrigation regardless of irrigant used. OPW irrigation by means of syringe following instrumentation with 5% NaOCl showed a similar effect to that of 15% EDTA irrigation for removal of smear layer and debris.

Keywords: oxidative potential water (OPW), root canal debris, root canal irrigation, smear layer.

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Introduction

Thorough debridement of the root canal system is essential for successful endodontic treatment (Weine 1989a). Canal preparation should not only remove pulp tissue, necrotic debris, microorganisms, and infected dentine, but also facilitate the placement of a filling that will seal the apical foramen. The final objective of chemomechanical preparation is to provide clean, smooth dentinal walls to which the sealer can adhere.

It remains controversial whether the smear layer should be removed from root canals prior to filling. The smear layer may be beneficial since it reduces the permeability of dentine and prevents or slows the penetration of bacteria into the dentinal tubules (Dippel *et al.* 1981, Pashley *et al.* 1981). However, bacteria have already penetrated the dentinal tubules in an infected root canal and they may survive and multiply despite instrumentation. Olgart *et al.* (1974) concluded that the

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acid produced by microorganisms could dissolve the smear layer and pass into the dentinal tubules.

Ørstavik & Haapasalo (1990) have noted the importance of dentinal tubule patency since they reported that the presence of a smear layer inhibited the flow of medicaments into tubules, reducing their antibacterial effect. Root canal irrigation with a combination of NaOCl and EDTA is often used during root canal treatment to remove the smear layer. In general, irrigation to remove the smear layer should have an antimicrobial action and the ability to dissolve organic and inorganic tissues. In addition, it should not irritate the periapical tissue if accidentally expressed beyond the apex, and must be biocompatible with vital tissue.

Oxidative potential water (OPW) has been used extensively in Japan for household and agricultural disinfection because of its safety and bactericidal effectiveness. According to the manufacturers' claims, the antimicrobial and antiviral activities of OPW are sufficiently powerful to kill a wide variety of pathogens, including Methicillin Resitant Staphylococcus Aureus (MRSA) and HIV. The scientific basis for the development of the OPW is that microorganisms cannot survive in an aqueous environment with both low pH (less than 3) and high oxidation-reduction potential (greater than 0.9 V) (Becking *et al.* 1960).

Oxidative potential water is an electrochemically created, highly acidic water that accumulates in the anode compartment of Aquacida (NDX-250KH, Nihon Aqua Co., Ltd, Kyoto, Japan) after sodium chloride (added for consuming the OH^- ions) is added to water. It is the counterpart of alkaline water formed in the cathode compartment after the water there has consumed the H^+ ions. OPW is created electrochemically by the use of devices in which anode and cathode are separated by a membrane in order to form two compartments. Electrolysis of aqueous sodium chloride solution by the device can yield the acidic and oxidative electrolysed water (pH lower than 2.7 and oxidation-reduction potential higher than +1100 mV) at the anode side compartment, and the alkaline and reductive electrolysed water (pH higher than 11 and oxidation-reduction potential lower than −800 mV) at the cathode side. OPW has strong antimicrobial activity, killing viruses as well as bacteria, an unusually low pH of 2.7 or less, and oxidation-reduction potentials of 1050 mV or greater (Okuda *et al.* 1994). This is considerably greater than tap water, which, in Japan, averages 300 mV to 400 mV, and greater than several activated oxygen-containing antimicrobial constituents, such as HOCl and O_3. It has been confirmed that OPW can condition both enamel and dentine for bonding with composite resin because of its low pH (Inoue *et al.* 1994).

Oxidative potential water is well suited for dental treatment because of its low toxicity and lack of irritation to soft tissues, and because it quickly loses its high oxidation-reduction potential and low pH when it reacts with light-sensitive and/or organic substances. For these reasons it is completely safe as a root canal irrigant. A previous study (Hata *et al.* 1996) showed that OPW effectively removed the smear layer from instrumented canal walls when used as an irrigant.

The aim of this study was to determine the optimum volume of OPW that should be used during irrigation, via a syringe and the optimum time for ultrasonic irrigation during root canal treatment to remove the smear layer from prepared root canal walls following instrumentation.

Materials and methods

One hundred and twenty extracted, single-rooted human maxillary teeth were used. The crowns were removed at the cementoenamel junction with a diamond disc, and a size 10 or 15 K-Flex file (Kerr Manufacturing Co., Romulus, MI, USA) was introduced into the canal until it could be seen just at the apical foramen. The working length was set 1.0 mm short of that position. The roots were divided into two groups of 60 roots each based on the irrigation method to be used. Syringe irrigation was used in the first (group S), whilst ultrasonic irrigation was used in the second (group U).

Syringe irrigation (group S)

The 60 samples were divided into four groups of 15 each. The canals of the first three groups (groups S-1 to S-3) were instrumented using K-Flex files (Kerr Manufacturing Co.) with 5% NaOCl as working solution, whilst the canals of the remaining group (group S-4) were instrumented using K-Flex files with OPW as working solution. All canals were instrumented by the conventional step-back preparation technique suggested by Weine (Weine 1989a). The canal orifices were flared with Gates Glidden burs to size 2 or 3, employing circumferential filing. Every time preparation was completed by each file, the root canal was washed out with fresh working solution using a 1-mL root canal syringe (Neo Dental Products Co., Ltd. Tokyo, Japan). Thus, each root canal was always flooded with either 5% NaOCl or OPW during canal instrumentation. All apical preparations were enlarged three sizes beyond the size of the

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Table 1 Irrigants used during and after mechanical cleaning with syringe and ultrasonic irrigation

Group	Working solution	Irrigation solution	Volume or application time of irrigation solution
S1	5% NaOCl	Distilled water	10 ml, 20 ml, 30 ml (5 teeth each)
S2	5% NaOCl	OPW	10 ml, 20 ml, 30 ml (5 teeth each)
S3	5% NaOCl	15% EDTA	10 ml, 20 ml, 30 ml (5 teeth each)
S4	OPW	OPW	10 ml, 20 ml, 30 ml (5 teeth each)
U1	5% NaOCl	Distilled water	1 min, 3 min, 5 min (5 teeth each)
U2	5% NaOCl	OPW	1 min, 3 min, 5 min (5 teeth each)
U3	5% NaOCl	15% EDTA	1 min, 3 min, 5 min (5 teeth each)
U4	OPW	OPW	1 min, 3 min, 5 min (5 teeth each)

[a]OPW, oxidative potential water.

first file that bound at the full working length, resulting in master apical file sizes ranging from size 45 to 60. After instrumentation, the apical foramen of each canal was sealed with sticky wax and a size 10 K-Flex file was passed into the canal through the foramen so that the tip of the file created a standardized opening.

After instrumentation, the groups were divided into three subgroups of five roots each that were irrigated as follows: group S-1 (control), three subgroups of five roots each were irrigated with 10, 20, and 30 mL of distilled water, respectively. Group S-2, three subgroups of five roots each were irrigated with 10, 20, and 30 mL of OPW, respectively. Group S-3, three subgroups of five roots each were irrigated with 10, 20, and 30 mL of 15% EDTA, respectively. Group S-4, three subgroups of five roots each were irrigated with 10, 20, and 30 mL of OPW, respectively.

The composition of the 15% EDTA solution was: 17 g disodium salt of EDTA, 100 mL distilled water, and 9.25 mL of 5 N sodium hydroxide. Final irrigation was carried out by flushing with the irrigants using a 22-gauge needle attached to a 10-mL syringe that was placed as far as possible into each canal short of binding. During final irrigation, the needle was continuously moved in and out, whilst being rotated through a 120° arc.

Ultrasonic irrigation (U group)

The remaining 60 roots were divided into four groups of 15 roots each, and were instrumented in the same way as the S group: the root canals of groups U-1, U-2, and U-3 were instrumented with 5% NaOCl, whilst those of group U-4 were instrumented with OPW as working solution. Each group of 15 roots was further divided into three subgroups of five roots each and were irrigated with an ultrasonic unit with a size 30 file (Enac, Osada Electric, Tokyo, Japan). Group U-1 (control), three subgroups of five roots each were irrigated with distilled water for 1, 3, and 5 min, respectively. Group U-2, three subgroups of five roots each were irrigated with OPW for 1, 3, and 5 min, respectively. Group U-3, three subgroups of five roots each were irrigated with 15% EDTA for 1, 3, and 5 min, respectively. Group U-4, three subgroups of five roots each were irrigated with OPW for 1, 3, and 5 min, respectively. During ultrasonic irrigation, each test irrigant was introduced continually in the root canal and access cavities by means of 10 mL syringe, and a size 30 file attached to the ultrasonic unit was placed in the apical third of the canal with the power knob set to ENDO 1. The solutions and irrigation methods were group-dependent and are summarized in Table 1.

Preparation for SEM examination

The canals were not dried following preparation so as to retain the existing condition of the walls. The specimens were stored in 70% ethanol in preparation for SEM examination.

The sticky wax was removed and longitudinal grooves were cut on the buccal and lingual surfaces with a diamond disc so as not to penetrate the canal. Each root was split in two with cutting pliers and prepared for SEM observation. The specimens were dehydrated by graded concentrations of ethanol and freeze-dried with t-butyl alcohol. They were then mounted on aluminium stubs, coated with 20-nm platinum-palladium using an Ion Sputter (E-1030, Hitachi, Tokyo, Japan), and stored in a desiccating cabinet to maintain dryness until SEM observation.

A scanning electron microscope (Hitachi S-450, Hitachi, Tokyo, Japan) operated at 20 kV was used to view the specimens. Photomicrographs were taken of the middle and apical thirds of all specimens at a magnification of ×1500. The photomicrographs were evaluated

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Table 2 Score for amount of remaining smear layer

Score	Tubules opened	Smear layer
0	All	None
1	>50%	Little
2	<50%	Moderate
3	Indistinguishable	Heavy

separately by three of the four authors using the rating system developed by Gorman *et al.* (1995). Both the amount of remaining smear layer and amount of debris were evaluated. The smear layer was scored 0–3 (0: no organic smear layer with all the tubules open; 1: little smear layer with greater than 50% of the tubules open; 2: moderate smear layer with less than 50% of the tubules open; and 3: heavy smear layer with no tubule outlines visible) (Table 2). The amount of pulpal debris was also graded from 0 to 3 (0: no debris; 1: minimal; 2: moderate; 3: heavy). Scores were averaged to obtain an overall cleanliness rating for the middle and apical third of the canal for all groups. The scores were statistically evaluated using the Student's *t*-test to determine the usefulness of OPW as an irrigant.

Results

The scores for smear layer and debris removal are shown in Tables 3–6.

Syringe irrigation group

Group S-1: Irrigation with distilled water after instrumentation with 5% NaOCl

The smear layer was present and obscured the dentinal tubules. Smear layer was seen at all levels in the canal, although a few dentinal tubules were visible in some specimens (Fig. 1a,b, mean scores were 2.0 and 1.4, respectively). Distilled water was effective at removing debris in the middle third of the canal, regardless of the volume of irrigation solution. The mean scores of debris removal using syringe irrigation were 1.1 by 10 mL,

Table 3 Mean score (±SD) for smear remaining after syringe irrigation

		Volume (ml)		
	Group	10	20	30
Middle third	S1	*2.0(0.5)*	*1.4(0.9)*	*1.8(0.9)*
	S2	*0.4(0.5)*	*0.8(1.1)*	*1.0(1.2)*
	S3	*0.4(0.5)*	*0.1(0.3)*	*0.6(0.7)*
	S4	*2.0(0.5)*	*1.4(0.9)*	*1.8(0.9)*
Apical third	S1	*3.0(0.0)*	*2.9(0.3)*	*3.0(0.0)*
	S2	*1.7(1.2)*	*2.0(1.0)*	*1.4(1.4)*
	S3	*1.7(1.0)*	*1.0(0.9)*	*1.2(0.9)*
	S4	3.0(0.0)	*2.4(0.7)*	*2.1(0.7)*

[a]Values in italics were not significantly different at $P < 0.05$.

Table 4 Mean score (±SD) for debris remaining after syringe irrigation

		Volume (ml)		
	Group	10	20	30
Middle third	S1	*1.1(0.3)*	*1.1(0.7)*	*1.3(0.8)*
	S2	*0.1(0.3)*	0.8(0.4)	*0.1(0.3)*
	S3	*0.8(0.6)*	*0.5(0.7)*	*0.8(0.9)*
	S4	*1.1(0.3)*	*1.1(0.7)*	*1.3(0.8)*
Apical third	S1	*1.8(0.7)*	*1.5(1.1)*	*1.1(0.6)*
	S2	*0.1(0.3)*	0.6(0.5)	*0.0(0.0)*
	S3	*1.1(0.8)*	*0.9(0.6)*	*1.0(0.5)*
	S4	*1.5(0.8)*	*1.2(0.4)*	*1.2(0.6)*

[a]Values in italics were not significantly different at $P < 0.05$.

Table 5 Mean score (±SD) for smear remaining after ultrasonic irrigation

		Duration (min)		
	Group	1	3	5
Middle third	U1	*2.3(0.7)*	*2.2(0.4)*	*2.1(0.6)*
	U2	*1.5(1.0)*	*1.4(0.7)*	*1.4(0.5)*
	U3	*0.8(0.9)*	*0.4(0.5)*	*0.7(0.5)*
	U4	*2.1(0.6)*	*2.2(0.4)*	*2.1(0.3)*
Apical third	U1	*2.6(0.5)*	*2.2(0.4)*	*2.4(0.5)*
	U2	*2.2(1.0)*	*1.7(0.7)*	*1.8(0.4)*
	U3	*1.1(0.7)*	*1.5(0.5)*	*1.1(0.6)*
	U4	*2.5(0.5)*	*2.8(0.4)*	*2.3(0.7)*

[a]Values in italics were not significantly different at $P < 0.05$.

Table 6 Mean score (±SD) for debris remaining after ultrasonic irrigation

		Duration (min)		
	Group	1	3	5
Middle third	U1	*0.4(0.5)*	*0.3(0.5)*	*0.8(0.7)*
	U2	*0.6(0.5)*	*0.6(0.5)*	0.1(0.3)
	U3	*0.4(0.5)*	*0.3(0.5)*	*0.6(0.7)*
	U4	*1.0(0.7)*	*0.9(0.6)*	*1.0(0.8)*
Apical third	U1	*0.5(0.5)*	*0.5(0.5)*	*0.6(0.5)*
	U2	*0.5(0.9)*	*0.6(0.7)*	0.1(0.3)
	U3	*0.6(0.5)*	*0.5(0.5)*	*0.9(0.3)*
	U4	*0.9(0.7)*	*1.6(0.7)*	*1.0(0.7)*

[a]Values in italics were not significantly different at $P < 0.05$.

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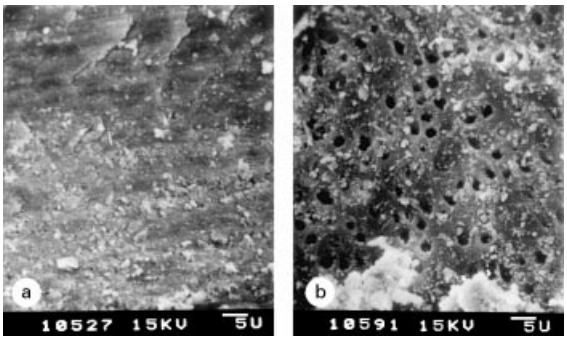

Figure 1 SEM photomicrographs of root canals in group S-1 irrigated with distilled water by syringe after instrumentation with 5% NaOCl. (a) Middle third of a root canal irrigated with 10 mL. A heavy, tightly adherent smear layer was present on the surface of every specimen. (b) Middle third of a root canal irrigated with 20 mL. Most of the superficial smear layer was retained and some tubule openings were visible.

1.1 by 20 mL, and 1.3 by 30 mL. However, in the apical third of the canal, debris removal improved as the volume increased (1.8 by 10 mL, 1.5 by 20 mL, and 1.1 by 30 mL) (Table 4).

Group S-2: Irrigation with OPW after instrumentation with 5% NaOCl

The middle third of the canal in this group showed a clean and smear-free surface with open and patent dentinal tubules; the dentinal tubules of the apical portion of the canal were covered by a thin smear layer (Fig. 2a,b). The mean scores of smear removal in the middle third of the root canal were 0.4 by 10 mL, 0.8 by 20 mL, and 1.0 by 30 mL of OPW, respectively, whereas the mean scores in apical third were 1.7 by 10 mL, 2.0 by 20 mL, and 1.4 by 30 mL, respectively (Table 3).

Irrigation with 30 mL of OPW removed completely the smear layer and debris in some specimens and created funnelling at the orifices of the dentinal tubules (Fig. 2c,d). The mean scores of debris removal by syringe irrigation using 30 mL of OPW were 0.1 in the middle third, and 0.0 in the apical third of the root canal (Table 4).

Group S-3: Irrigation with 15% EDTA after instrumentation with 5% NaOCl

In this group, the syringe irrigation using 20 mL of 15% EDTA showed the most effective smear removal ability in the middle third of the root canal with mean score 0.1.

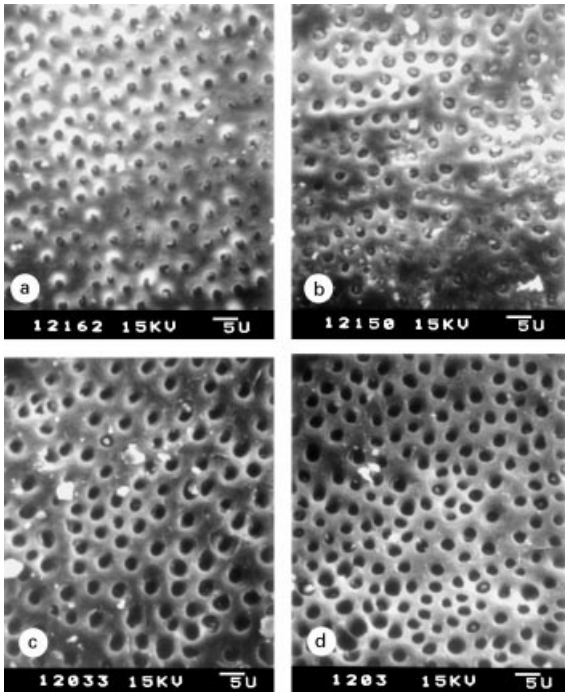

Figure 2 SEM photomicrographs of root canals in group S-2 irrigated with OPW by syringe after instrumentation with 5% NaOCl. (a) Middle third of a root canal irrigated with 10 mL. (b) Apical third of a root canal irrigated with 20 mL. Dentinal tubules were open, although occasionally blocked by smear plugs. (c, d) Middle and apical thirds of a root canal irrigated with 30 mL. Syringe irrigation with OPW removed the superficial smear layer and debris from the canal wall.

Although the combination of 5% NaOCl and 15% EDTA produced smear-free canal walls in the middle third of the canal, a smear layer was sometimes present covering the dentinal tubules in the apical third (Fig. 3a,b). These findings were similar to those for group S-2.

A high volume of irrigation solution produced a score of 0 for smear and debris removal in some specimens, with the greatest demineralizing effect on the dentine resulting in funnelling of the tubule orifices and widening of their lumina (Fig. 3c,d).

Group S-4: Irrigation with OPW after instrumentation with OPW

Oxidative potential water had a moderate effect on smear removal, opening the dentinal tubules beneath the retained superficial smear layer (Fig. 4a,b). The mean score of smear removal after syringe irrigation using 10 mL was 2.0 in the middle third of the root

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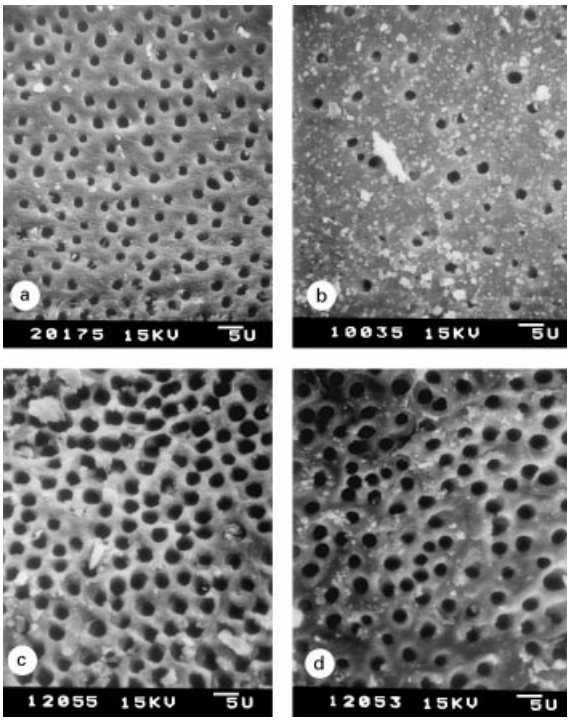

Figure 3 SEM photographs of root canals in group S-3 irrigated with 15% EDTA by syringe after instrumentation with 5% NaOCl. (a, b) Middle and apical thirds of a root canal irrigated with 10 mL. Although the middle third of the root canal showed a smear-free surface, dentinal tubules in the apical third were partially obliterated by the smear layer. (c, d) Middle and apical thirds of a root canal irrigated with 30 mL. The demineralizing effect on the dentine resulted in funnelling of the orifices of the tubules and widening of their lumina.

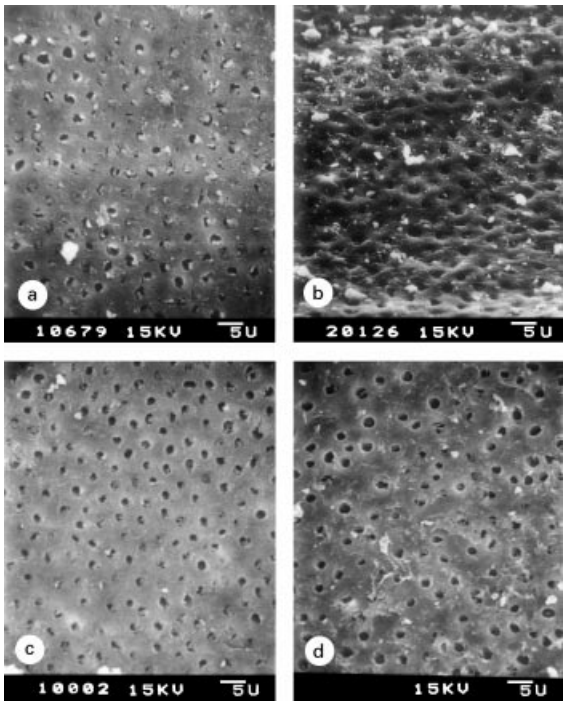

Figure 4 SEM photographs of root canals in group S-4 irrigated with OPW by syringe after instrumentation with OPW. (a) Middle third of a root canal irrigated with 10 mL. The smear layer was partially present, but some orifices of dentinal tubules were exposed. (b) Apical third of a root canal irrigated with 20 mL. The smear layer appeared thin, so that the outline of the tubules could be observed. (c, d) Middle and apical thirds of a root canal irrigated with 30 mL. Although the smear layer was removed, orifices of dentinal tubules were not well defined.

canal. Although the effect of smear removal increased in the apical third of the canal with high volumes of irrigation solution, some of the dentinal tubules were blocked by smear plugs (Fig. 4c,d). There was significant difference in smear removal effect amongst the volume used in syringe irrigation. The mean scores in the apical third of the root canal were 3.0 by 10 mL, 2.4 by 20 mL, and 2.1 by 30 mL, respectively (Table 3).

Ultrasonic irrigation group

Group U-1: Irrigation with distilled water after instrumentation with 5% NaOCl

The scores for smear removal in this group were similar to those in group S-1 irrigated by the syringe. The mean scores in the middle third of the root canal were 2.3 for 1 min, 2.2 for 3 min, and 2.1 for 5 min, respectively. There was no smear removal in this group regardless of the duration of ultrasonic irrigation (Fig. 5a,b) (Table 5). However, debris removal in this group was superior to that in the syringe irrigation group (Table 6).

Group U-2: Irrigation with OPW after instrumentation with 5% NaOCl

The mean score of smear removal after ultrasonic irrigation for 1 min was 1.5 in the middle third and 2.2 in the apical third of the root canal. Smear removal was less effective than in the same group with syringe irrigation (Fig. 6a,b) (Table 5).

Smear removal improved with increased duration of application, although residual debris resembling odontoblastic processes were left in some dentinal tubules

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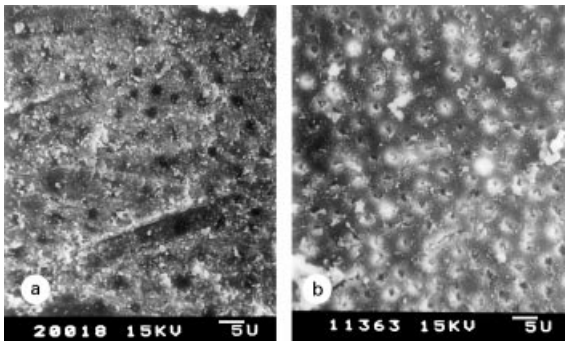

Figure 5 SEM photographs of root canals in group U-1 irrigated with distilled water by applying ultrasound after instrumentation with 5% NaOCl. (a) Apical third of a root canal irrigated for 1 min. A heavy smear layer was present at all levels in all specimens. (b) Apical third of a root canal irrigated for 5 min. A thin smear layer was present, although debris was absent.

(Fig. 6c,d). Debris removal was most effective in the ultrasonic irrigation group. There was significant difference in removing debris amongst the duration of ultrasonic irrigation in both in the middle and apical third of the root canal (Table 6).

Group U-3: Irrigation with 15% EDTA after instrumentation with 5% NaOCl

Smear removal was most effective throughout the entire root canal in the ultrasonic irrigation group. Dentinal walls irrigated for 1 min were covered with a superficial smear layer in some areas that obscured the dentinal tubules. The mean scores of smear removal in the middle third of the root canal were 0.8 and 1.1 in the apical third of the root canal (Fig. 7a,b).

Dentinal walls irrigated for 5 min showed clean surfaces in the middle third of the root canal and the lumen of the dentinal tubules appeared larger in diameter at the expense of the peritubular and intertubular dentine. However, no patent tubular orifices could be seen on the dentinal wall at the apical third (Fig. 7c,d).

Group U-4: Irrigation with OPW after instrumentation with OPW

The mean scores of smear removal after ultrasonic irrigation for 1 min were 2.1 in the middle third and 2.5 in the apical third of the root canal. In this group, there was no effect on smear removal regardless of the duration of ultrasonic irrigation (Table 5).

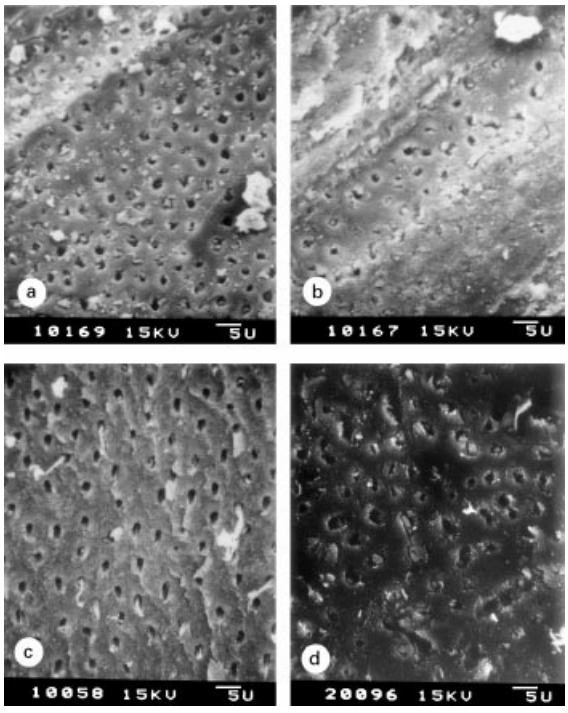

Figure 6 SEM photographs of root canals in group U-2 irrigated with OPW by applying ultrasound after instrumentation with 5% NaOCl. (a, b) Middle and apical thirds of a root canal irrigated for 1 min. The specimens from the middle third showed a smear-free surface, although an adherent smear layer was present on the canal wall of the apical third. (c) Middle third of a root canal irrigated for 3 min. Dentinal tubules were exposed, and residual debris resembling odontoblastic processes was seen. (d) Apical third of a root canal irrigated for 5 min. The surface of canal wall showed no smear layer, although the orifices of dentinal tubules were not well defined.

A superficial smear layer covered the surface of dentinal wall at all levels, and dentinal plugs were present, obscuring the tubules (Fig. 8a,b). Regardless of the use of ultrasound, the superficial smear layer was pervasive in all specimens (Fig. 8c,d).

There was no significant difference in root canal debridement between the various volumes used in syringe irrigation. Although the irrigation technique did not remove smear layer in groups S-1 (distiilled water following 5% NaOCl) and S-4 (OPW during and after instrumentation), it had considerable effect in groups S-2 (OPW after instrumentation with 5% NaOCl) and S-3 (15% EDTA after instrumentation with 5% NaOCl).

The irrigation techniques for group S-2 (OPW after

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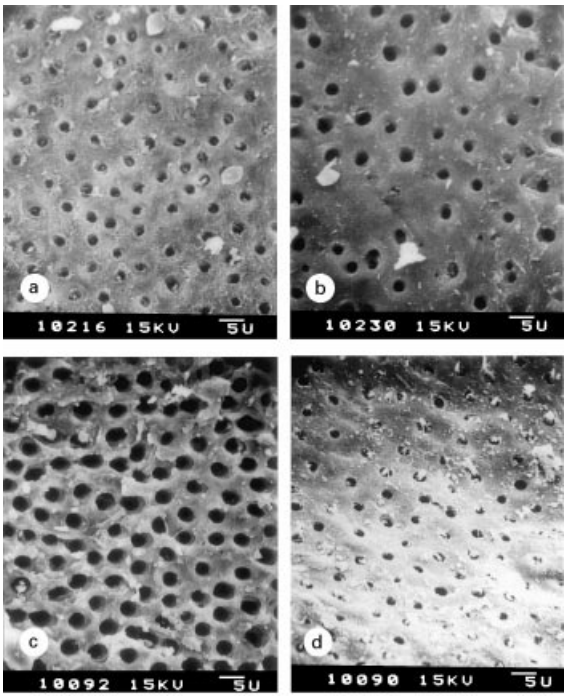

Figure 7 SEM photographs of root canals in group U-3 irrigated with 15% EDTA by applying ultrasound after instrumentation with 5% NaOCl. (a, b) Middle and apical thirds of a root canal irrigated for 1 min. The canal walls were relatively clean, although some debris was present. (c, d) Middle and apical thirds of a root canal irrigated for 5 min. (c) the specimen from the middle third of a root canal showed enlargement of orifices at the expense of the peritubular and intertubular dentine. (d) Apical third of a root canal showed a smear-free surface, although residual debris resembling odontoblastic processes were seen in the exposed dentinal tubules.

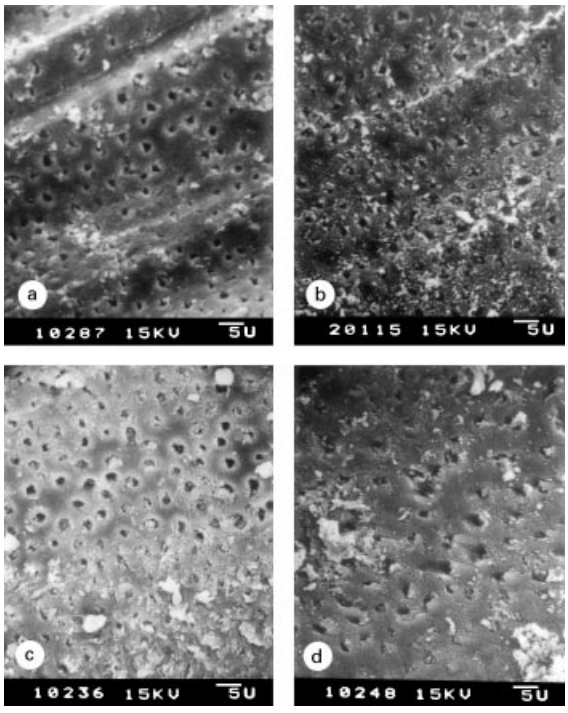

Figure 8 SEM photographs of root canals in group U-4 irrigated with OPW by applying ultrasound after instrumentation with OPW. (a) Middle third of a root canal irrigated for 1 min. (b) Apical third of a root canal irrigated for 3 min. The superficial smear layer was removed from both surfaces, although the orifices of dentinal tubules were not well defined. (c, d) Middle and apical thirds of a root canal irrigated for 5 min. Although a few dentinal tubules were visible, the smear layer obscured the dentinal tubules. There were bits of organic and inorganic debris.

instrumentation with 5% NaOCl) were the most effective for removing debris. The apical third of the canal was significantly cleaner than the middle third for all specimens.

Ultrasonic irrigation was more effective for removing debris than smear layer removal from root canal wall.

Discussion

The significance of the smear layer covering the entire root canal wall remains controversial. From the restorative dentistry perspective, the role of smear layer acting as a physical barrier to bacteria and bacterial by-products has been supported by Michelich *et al.* (1980) and Diamond & Carrel (1984). They showed that bacteria could not penetrate into dentine when a smear layer was present. Brännström & Nyborg (1974) showed that there were bacteria in the smear layer and that they multiplied and produced toxins that were harmful to the pulp. According to William & Goldman (1985), who confirmed the permeability of the smear layer *in vitro* using a model system utilizing the highly motile Proteus organism, the smear layer simply delayed the penetration of this microorganism. They also reported that when the root canal became heavily infected, bacteria might be found deep in the dentinal tubules and that the smear layer found on root canal walls after endodontic instrumentation would contain remnants of necrotic pulp tissue and bacteria. Goldberg & Abramovich (1977) stated that the smear layer might prevent the penetration of intracanal disinfectants and filling materials into dentinal tubules, suggesting that chemomechanical

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cleaning should be supported by the use of disinfectants. Byström & Sundqvist (1985) have confirmed the antibacterial effect of sodium hypochlorite and EDTA during chemomechanical cleaning and demonstrated that a supporting action of a disinfectant was necessary for successful extermination of living bacteria from root canals. Oksan *et al.* (1993) suggested that the chemical and physical characteristics of root canal sealers might affect tubular penetration and adaptation of the material to the root canal wall following the removal of smear layer. Gençoglu *et al.* (1993) demonstrated that removing the smear layer significantly reduced apical leakage in the groups obturated with thermoplasticized gutta-percha techniques. For these reasons, the smear layer could be considered deleterious and that it should be removed during root canal treatment.

In the early stages of instrumentation, it is probable that the smear layer will have a relatively high organic pulpal content, whereas when instrumentation progresses, the smear layer could become more inorganic in nature.

Various irrigating solutions and their combinations are used for removing the smear layer from root canal walls. However, no single irrigant has been found to dissolve organic pulpal material and predentine or to demineralize the inorganic calcified portion of the canal wall. Therefore, the combination of EDTA and sodium hypochlorite is used for irrigation of the root canal during instrumentation.

Sodium hypochlorite has been used for many years as an adjunct to biomechanical preparation (Weine 1989b). This solution is effective as an antimicrobial agent and a 5% or lower solution is one of the most commonly used root canal irrigants.

Cunningham & Martin (1982) reported the effectiveness of ultrasonic irrigation, and demonstrated that ultrasonically prepared specimens were significantly cleaner, with the smear layer greatly reduced. In their study, they suggested that the NaOCl, warmed by the ultrasonic generator, had an effective solvent action on collagen. The heat generated by ultrasonic activation would warm the irrigating solution in the root canal from root temperature to body temperature.

According to Kaufman & Greenberg (1986), a working solution is used to clean and to shape the canal, and an irrigation solution is the one which is essential to remove the debris and smear layer created by the instrumentation process. In the present study, NaOCl was not used as an irrigation solution, but it was used as a working solution without the application of ultrasonics. Therefore, NaOCl might not exhibit such an effective solubility as has been reported. However, the use of NaOCl as a working solution may be indispensable to achieve canal sterilization during instrumentastion due to its nonspecific antimicrobial activity.

Oxidative potential water has recently been studied in Japan and is known to suppress the growth of bacteria and viruses without harming living systems. Its physical properties are as follows; pH: 2.7–2.3; oxidative-reduction potential: 1000–1100 mV; dissolved chlorine: 30–40 p.p.m. and dissolved oxygen: 10–30 p.p.m. In addition, its demineralizing effect of tooth structure has been reported (Inoue *et al.* 1994).

Irrigation via a syringe, particularly with a large volume of irrigant, created effective fluid flow and circulation in the canal system. On the other hand, the ultrasonic irrigation in the present study may not have provided sufficient fluid movement within the canal system, because the power knob of the device was set to a minimal level for fear that the file would break in the canal. As a result, the present study showed that ultrasonic irrigation with OPW was less effective in removing the smear layer than syringe irrigation. However, the debridement capability by ultrasonic activation seemed more effective in flushing out loose debris from the root canals. The present study showed that ultrasonic irrigation with OPW was less effective in removing the smear layer than syringe irrigation with OPW. Cameron (1988) found that ultrasonic water irrigation had no apparent effect on the smear layer, so it would appear that ultrasound per se does not mechanically remove the smear layer. However, we have reported on the ability of OPW to remove the smear layer after root canal instrumentation and found that irrigation with OPW and a syringe was deemed useful for root canal irrigation (Hata *et al.* 1996). In the present study, it was demonstrated that OPW irrigation after root canal instrumentation (both in groups S-2 and U-2) effectively removed the smear layer. The findings were similar to those in groups S-3 and U-3, which were irrigated with 15% EDTA after root canal instrumentation. The canal walls prepared in both groups showed open and patent dentinal tubules and the surfaces in some specimens were irregular and bumpy with no smear layer.

Conclusions

In this study, the most effective irrigation technique for smear removal was 15% EDTA irrigation by means of syringe following instrumentation with a 5% NaOCl solution. However, the most effective irrigation technique for debris removal was ultrasonic irrigation regardless of irrigant used. OPW irrigation by means of syringe

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following instrumentation with a 5% NaOCl showed similar effect to that by 15% EDTA irrigation concerning removal of smear layer and debris.

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