Cleaning effectiveness of root canal irrigation with electrochemically activated anolyte and catholyte solutions: a pilot study

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Abstract

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Aim The aim of this study was to evaluate the potential of electrochemically activated (ECA) anolyte and catholyte solutions to clean root canals during conventional root canal preparation.

Methodology Twenty extracted single-rooted human mature permanent teeth were allocated randomly into four groups of five teeth. The pulp chambers were accessed and the canals prepared by hand with conventional stainless steel endodontic instruments using a double-flared technique. One or other of the following irrigants was used during preparation: distilled water, 3% NaOCl, anolyte neutral cathodic (ANC) (300 mg L^{-1} of active chlorine), and a combination of anolyte neutral cathodic (ANC) (300 mg L^{-1} of active chlorine) and catholyte. The teeth were split longitudinally and the canal walls examined for debris and smear layer by scanning electron microscopy. SEM photomicrographs were taken separately in the coronal, middle and apical parts of canal at magnification of ×800 to evaluate the debridement of extracellular matrix and at a magnification of ×2500 to evaluate the presence of smear layer.

Results Irrigation with distilled water did not remove debris in the apical part of canals and left a continuous and firm smear layer overlying compressed low-mineralized predentine. All chemically active irrigants demonstrated improved cleaning potential compared to distilled water. The quality of loose debris elimination was similar for NaOCl and the anolyte ANC solution. The combination of anolyte ANC and catholyte resulted in improved cleaning, particularly in the apical third of canals. The evaluation of smear layer demonstrated that none of the irrigants were effective in its total removal; however, chemically active irrigants affected its surface and thickness. Compared to NaOCl, the ECA solutions left a thinner smear layer with a smoother and more even surface. NaOCl enhanced the opening of tubules predominantly in the coronal and middle thirds of canals, whereas combination of ANC and catholyte resulted in more numerous open dentine tubules throughout the whole length of canals.

Conclusions Irrigation with electrochemically activated solutions cleaned root canal walls and may be an alternative to NaOCl in conventional root canal treatment. Further investigation of ECA solutions for root canal irrigation is warranted.

Keywords: cleaning, debridement, electrochemically activated solutions, root canal.

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Introduction

Elimination of microorganisms from the root canal system is one of the objectives of root canal treatment (Byström *et al.* 1987) and has a substantial effect on the outcome (Lin *et al.* 1992, Sundqvist *et al.* 1998). Unfortunately, microorganisms may remain after conventional canal preparation, either within the dentine tubules (Peters *et al.* 1995), embedded in the smear layer (Huque *et al.* 1998) or bound within the apical dentine plug (Nair *et al.* 1990, Abou-Rass & Bogen 1998).

It is generally believed that mechanical enlargement

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of canals must be accompanied by copious irrigation in order that the prepared canal becomes as bacteria-free as possible (Lin *et al.* 1992, Molander *et al.* 1998). Ideally an irrigant should provide a mechanical flushing action, be microbiocidal and dissolve remnants of organic tissues without damaging the periradicular tissues if extruded into the periodontium.

Numerous irrigants have been recommended for clinical use (Ørstavik & Pitt Ford 1998). Irrigation with distilled water or saline is effective in eliminating loose debris from the upper and middle thirds of the root canal, but they have little affect on the smear layer (Baumgartner & Mader 1987, Walker & del Rio 1991). Sodium hypochlorite (NaOCl) is widely recommended and is now the preferred irrigant in root canal treatment because of its microbiocidal and organic tissue-dissolving ability (Qualtrough *et al.* 1999). However, NaOCl does not effectively remove the smear layer (Berutti & Marini 1996, Bertrand *et al.* 1999), and many *in vitro* and *in vivo* studies have reported moderate to severe cytotoxicity when sodium hypochlorite solution in clinically recommended concentrations is extruded through the apex (Spångberg *et al.* 1973, Koskinen *et al.* 1981, Gatot *et al.* 1991, Yesilsoy *et al.* 1995, Koulaouzidou *et al.* 1999). Concern about this potentially dangerous side-effect has resulted in the recommendation that irrigating needles should be placed passively into the canal in order to prevent apical extrusion (Brown *et al.* 1995). Clearly, because of the potential toxicity of NaOCl, the investigation of alternative irrigants is important.

Electrochemically activated (ECA) solutions are produced from tap water and low-concentration salt solutions (Bakhir *et al.* 1986, Bakhir *et al.* 1989, Bakhir 1992). The ECA technology represents a new scientific paradigm developed by Russian scientists at the All-Russian Institute for Medical Engineering (Moscow, Russia, CIS). The ECA technology is based on the process of transferring liquids into a metastable state via an electrochemical unipolar (anode or cathode) action through the use of an element/reactor ('Flow-through Electrolytic Module' or FEM). The FEM consists of an anode, a solid titanium cylinder with a special coating that fits coaxially inside the cathode, a hollow cylinder also made from titanium with another special coating. A ceramic membrane separates the electrodes. Electrochemical treatment in the anode and cathode chambers of the diaphragm electrolyzer (for unipolar electrochemical treatment) transforms water and low mineral solutions into a metastable state that is characterized by modified values of physical-chemical parameters, particularly, the pH and oxidation-reduction potential (φ). These parameters appear to change spontaneously in a period of time after the electrochemical activation. Transition from the thermodynamically non-equilibrated condition to stable values is defined as the period of relaxation. The FEM is capable of producing types of solutions that have bactericidal and sporicidal activity, yet are odourless, safe to human tissue and essentially noncorrosive for most metal surfaces (Selkon *et al.* 1999, Shetty *et al.* 1999). FEMs have been incorporated into a variety of delivery systems (devices) for creating electrochemically activated solutions. The ECA devices have been in widespread commercial use in Russia and the Commonwealth of Independent States for a number of years, mainly in the areas of hospital disinfection, sterilization, and in agricultural and industrial processes. There are over 60 000 ECA devices in use in Russia today.

Electrochemical treatment in the anode and cathode chambers results in the synthesis of two types of solutions, that produced in the anode chamber is termed an anolyte; and that produced in the cathode chamber is catholyte. Anolyte solutions containing a mixture of oxidizing substances demonstrate pronounced microbiocidal effectiveness against bacteria, viruses, fungi and protozoa (Prilutskii *et al.* 1996, Bakhir *et al.* 1999). The anolyte solution has been termed Super-Oxidized Water (Selkon *et al.* 1999) or Oxidative Potential Water (Hata *et al.* 1996). Depending on the type of FEM, the pH of anolyte varies; it may be acidic (anolyte), neutral (anolyte neutral) or alkaline (anolyte neutral cathodic); acidic anolyte was used initially but in recent years the neutral and alkaline solutions have been recommended for clinical application.

Significant microbiocidal activity of a Super-Oxidized Water was demonstrated against *Escherichia coli* (including type 0157), *Pseudomonas aeruginosa*, *Bacillus subtilis var niger* spores, methicillin-resistant *Staphylococcus aureus*, *Clostridium difficile* spores, *Helicobacter pylori*, vancomycin resistant Enterococcus species, *Candida albicans*, several Mycobacterium species and human immunodeficiency virus HIV-1. Under clean conditions, freshly generated Super-Oxidized solution was found to be highly active against all these microorganisms giving a 99.999% or greater reduction in 2 min or less. That allowed investigators to treat it as a potent microbiocidal agent (Selkon *et al.* 1999, Shetty *et al.* 1999). It is nontoxic when in contact with vital biological tissues (Shraev & Legchilo 1989, Shraev *et al.* 1993). Clinical applications of anolyte and catholyte were reported to be effective (Deviatov & Petrov 1992, Deviatov *et al.* 1993, Malakhov *et al.* 1994, Legchilo *et al.* 1996, Melnikova *et al.* 1997).

1 Anolyte neutral (AN): produced in the anode chamber, pH = 6.0 ± 1.0; oxidation-reduction potential φ – from +600 to +900 mV, total mineral content

c = 0.3–5 gL^{-1}, main biocidal reagents: HOCl, ClO^-, ClO, H_2O_2. Microbiocidal potential of anolyte is provided by the presence of active chlorine, a well known strong oxidizing agent.

2 Anolyte neutral cathodic (ANC): produced at the anode chamber, partially mixed with OH^- that is transferred through the membrane in the cathode chamber, pH = 7.7 ± 0.5; oxidation-reduction potential φ – from +250 to +800 mV, total mineral content c = 0.3–5 gL^{-1}, main biocidal reagents: HOCl, ClO, HO_2, $^1O_2$. In comparison to AN, the anolyte neutral cathodic (ANC) solution contains a higher concentration of peroxides and demonstrates an increased antiseptic effect at lower concentrations of active chlorine and increased cleaning ability (Bakhir *et al*. 1999).

3 Catholyte is an alkaline solution with oxidation-reduction potential. It is characterized by a pH value >9, oxidation-reduction potential φ – from –700 to –820 mV, total mineral content c = 0.3–5 gL^{-1}. Main biocidal reagents: OH^-, H_2O_2, and NaOH provide a strong cleaning or detergent effect of catholyte: it dissolves necrotic tissue being safe for vital tissues (Prilutskii & Bakhir 1997).

The objective of this study was to evaluate the cleaning effectiveness of root canal irrigation with electrochemically activated anolyte and catholyte solutions compared to sodium hypochlorite and distilled water.

Materials and methods

Teeth

Twenty freshly extracted single-rooted human permanent teeth with mature apices and with only limited loss of tooth tissue through caries or restoration were stored in 4% paraformaldehyde solution for 48 h and rinsed under running water before use. The teeth were divided randomly into four groups of five teeth.

Canal preparation

Endodontic access was achieved initially using a diamond bur in a turbine handpiece and completed with a BATT cone bur (Dentsply Maillefer, Ballaigues, Switzerland). Canal length was determined by inserting a size 15 K-file (Dentsply Maillefer) until its tip just appeared through the apical foramen and by adjusting the rubber stop to the coronal reference point. An individual working length for each tooth was established by subtracting 1 mm from the total length.

Orifice enlargement was achieved by preflaring the coronal third of the canal with Gates Glidden burs sizes 1–4 in a contra-angle handpiece (maximum speed 500 r.p.m.) using light push/pull strokes with constant movement of the bur. The apical two-thirds of root canals were instrumented manually using Flexofiles (Dentsply, Maillefer) in a modified double-flared technique (Saunders & Saunders 1992, Dummer *et al.* 1998); the balanced force technique of instrument manipulation was used. The apical portion of each root canal was enlarged to three ISO sizes larger than the initial instrument that bound at the working length. The apical portion was flared using a 'step-back' technique. Recapitulation with the master file to the working length was performed after every new size file.

Canal irrigation

During preparation all canals were irrigated profusely; the delivery of the solutions was standardized. The type of irrigating solution used during preparation varied between study groups:

1 Negative control group: distilled water. A high-volume flush with 10 mL of distilled water was carried out following coronal flaring with Gates Glidden burs. Irrigation with 1 mL of distilled water was performed for at least 10 s after every file. Following preparation a final flush with 10 mL of distilled water was carried out for a minimum of 30 s.

2 Positive control group: 3% solution of NaOCl (Parcan, Specialites Septodont, Saint-Maur-Des-Fosses, France). A high-volume flush with 10 mL of NaOCl was carried out following coronal flaring with Gates Glidden burs. Irrigation with 1 mL of NaOCl was performed for at least 10 s after every file. Following preparation a final flush with 10 mL of NaOCl was carried out for a minimum of 30 s.

3 Anolyte neutral cathodic (ANC) solution (with 300 mg L^{-1} active chlorine). The ANC solution was produced by a STEL-10H-120–01 device; a 0.3% NaCl solution in distilled water was used for electrochemical activation. The concentration of active chlorine was established at a level of 300 mg L^{-1}. The anolyte neutral cathodic solution was a transparent liquid with a mild odour of chlorine. A high-volume flush with 10 mL of ANC solution was carried out following coronal flaring with Gates Glidden burs. Irrigation with 1 mL of ANC solution was performed for at least 10 s after every file. Following preparation a final flush with 10 mL of ANC solution was carried out for a minimum of 30 s.

4 Alternate use of ANC solution (300 mg L^{-1} active chlorine) and catholyte solution. A high-volume flush with 10 mL of catholyte solution was carried out following coronal flaring with Gates Glidden burs. Irrigation with 1 mL of ANC anolyte was performed for at least 10 s

after every file. Following preparation a final flush with 10 mL of catholyte was carried out for a minimum of 30 s.

Each irrigant was delivered through an endodontic needle (Specialites Septodont) placed as deeply as possible into the canal lumen without binding. The canals were kept flooded with the irrigating solution throughout the instrumentation procedures, including orifice enlargement. Following the definitive irrigating regimen, traces of irrigating solution in all canals were flushed out with 10 mL of distilled water.

SEM evaluation of canal cleanliness

Immediately after instrumentation and irrigation, the teeth were split for evaluation of canal wall cleanliness. After amputation of the crown at the cemento-enamel junction, longitudinal grooves were cut on the mesial and distal surfaces of the roots without penetrating through to the canal using a wheel diamond bur. The roots were then split in two with cutting pliers; efforts were made to split the roots through the apical foramina. One side of each canal was chosen randomly for SEM evaluation. Specimens were placed into a dust-free incubator ready for SEM analysis.

For scanning electron microscopy the specimens were fixed on aluminium stubs (Agar Scientific, Essex, UK) with Leit C Plast carbon cement (Agar Scientific). After being air-dried the specimens were sputter coated with gold (SC500, Emscope, Kent, UK) and viewed with a scanning electron microscope (EBT EX B1, Electron Beam Technology, Derbyshire, UK).

The canal wall surfaces were scanned separately in the coronal, middle and apical parts using a standard protocol (Ciucchi *et al.* 1989). SEM photomicrographs of the most representative portion were taken at the following sites:

1 the border of coronal and middle thirds

2 the border of middle and apical thirds

3 the deep apical part 1.5–2 mm short of the apical foramen

4 the marginal angle between the longitudinal fracture line and root canal wall at the border of the middle and apical thirds (efforts were taken to choose the site with longitudinal fracture of dentine tubules)

Photomicrographs were taken at a magnification of ×800 to evaluate the debridement of extra-cellular matrix and at a magnification of ×2500 to evaluate the debridement of smear layer. In total, eight pictures per specimen were taken.

The debridement of extra-cellular matrix was evaluated taking into account the size and the number of loose debris particles as well as low-mineralized predentine compacted against the dentine walls. The removal of smear layer was evaluated taking into account the extent of smear layer elimination, its thickness, surface roughness and the incidence of open tubule orifices.

Results

Distilled water (negative control)

SEM observation of negative control specimens treated with distilled water revealed that the root canal surfaces differed depending on the level within the canal and therefore the type of instrumentation. In the coronal part of canal where the engine-driven Gates Glidden drills had been used, the smear layer was predominantly smooth with few areas of irregularity. Occasional openings of dentine tubules could be observed. The presence of free debris was obvious in all samples. In the coronal area the debris particles were small and scattered (Fig. 1).

In the middle third of the roots instrumented manually with Flexofiles a predominantly thick continuous smear layer remained. It had a smooth and dense surface that covered a partially compressed low-mineralized predentine layer that had a flaky consistency. Free debris was relatively sparse in this part of the root canals (Fig. 2A).

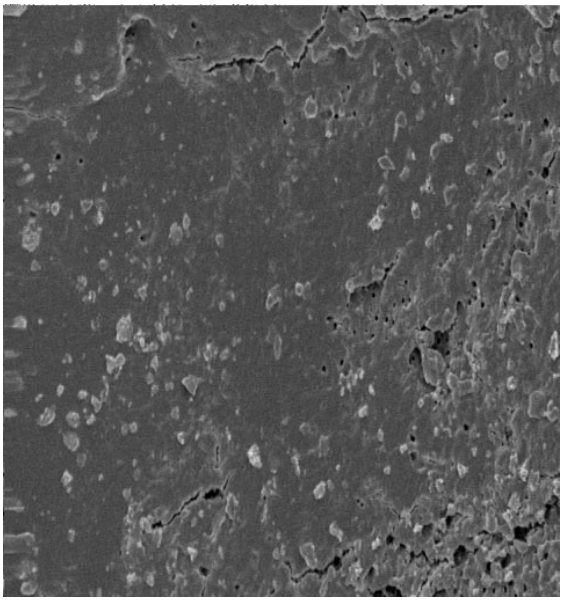
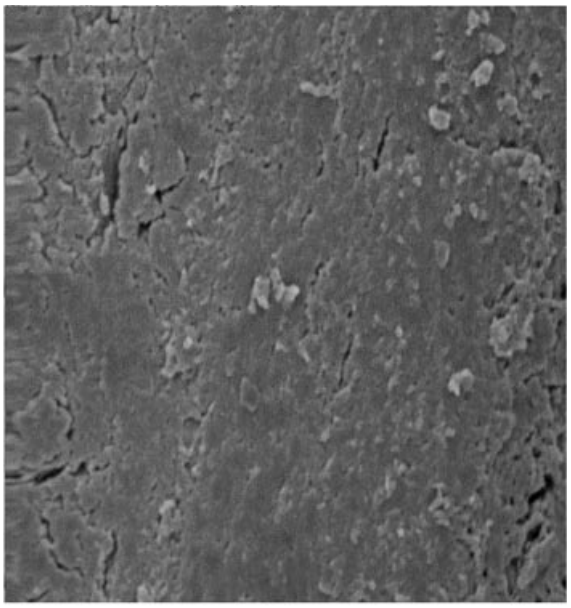


Figure 1 Coronal third of root canal instrumented by Gates Glidden burs and irrigated with distilled water (×800). Surface totally covered by a thick smooth smear layer with few partially open tubule orifices; scattered small loose debris.



(a)

(b)

Figure 2 Apical part of root canal instrumented manually by Flexofiles and irrigated with distilled water. (a) Middle third of canal wall (×2500) – smooth and dense smear layer covers compressed low-mineralized predentine with flaky consistency. Dentine tubule orifices are blocked. Scattered small loose debris. (b) Apical third of canal wall (×800) – irregular smear layer and extensive amounts of loose debris.

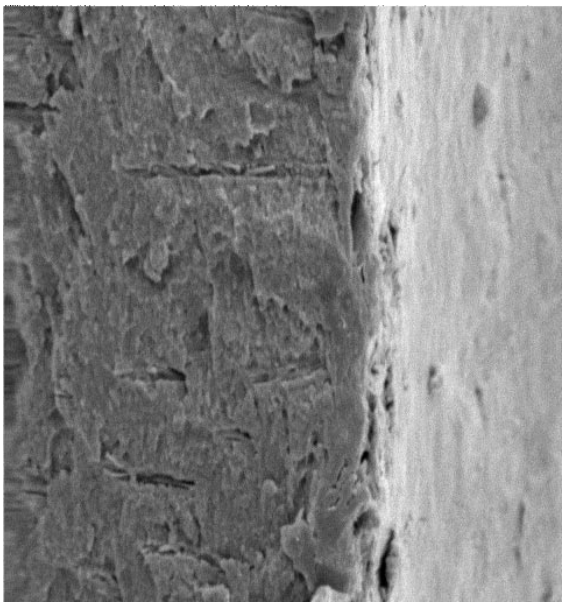


Figure 3 The marginal angle between longitudinal fracture line and lumen of root canal instrumented manually by Flexofiles and irrigated with distilled water (×2500). A thick layer of compressed low-mineralized dentine is attached to the dentine wall. Tubule orifices are blocked.

In the apical region areas of smooth smear layer interleaved with an irregular rough surface were apparent (Fig. 2B). The loose debris were larger in size and more numerous. Thick flaky layers of partially compressed porous dentine compacted against the dentine walls were detected in most specimens (Fig. 3).

NaOCl (positive control)

SEM analysis of specimens treated with 3.0% NaOCl revealed a smear layer in all specimens. As before, there were obvious differences in the appearance of the canal walls depending on the type of instrumentation. In the coronal third of canals the smear layer was removed partially with some tubule orifices being visible. The surface of the remaining smear layer was uniform and porous. Specimens demonstrated none or only a minor amount of loose debris on the root canal walls (Fig. 4).

In the middle third the appearance of the smear layer varied substantially; small areas of partially removed smear layer interleaved with areas of thick flaky smear layer. This region demonstrated a high incidence of open tubules (Fig. 5A).

In the apical part most specimens demonstrated a smooth continuous smear layer with blocked dentine

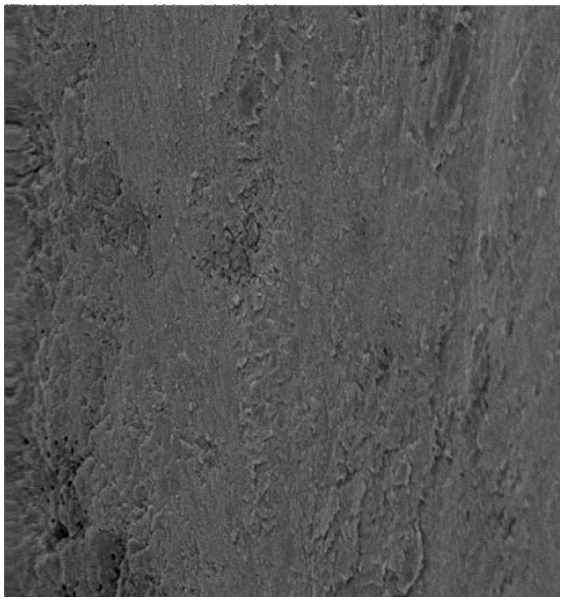


Figure 4 Coronal third of root canal instrumented by Gates Glidden burs and irrigated with 3.0% NaOCl (×800). Limited areas of the canal were free of smear layer and had open tubule orifices. The surface of the remaining smear layer is uniform and slightly porous; it is free of loose debris.

tubules. The middle and apical thirds of canal walls in most specimens contained none or only a limited amount of loose debris (Fig. 5B).

SEM observation of the marginal angle between the longitudinal fracture line and root canal wall did not reveal a substantial thickness of compressed predentine; smear layer and smear plugs in dentine tubule orifices were visible (Fig. 6).

Anolyte neutral cathodic (ANC) solution (300 mg L^{-1} active chlorine)

In specimens irrigated with ANC solution the texture of the canal wall surfaces was similar in the various parts of root canal. In the coronal third of canals instrumented by Gates Glidden burs the smear layer was smooth and slightly porous. Partially open tubule orifices were evenly distributed throughout the surface. Specimens demonstrated only sparse small loose debris on the root canal walls (Fig. 7).

In the middle part of the root canals instrumented manually by Flexofiles areas of thin smear layer with blocked and partly blocked tubule orifices were predominant, interleaved with the rough and porous thick smear layer. The dentine debris were not numerous, but were obvious in all specimens (Fig. 8A).

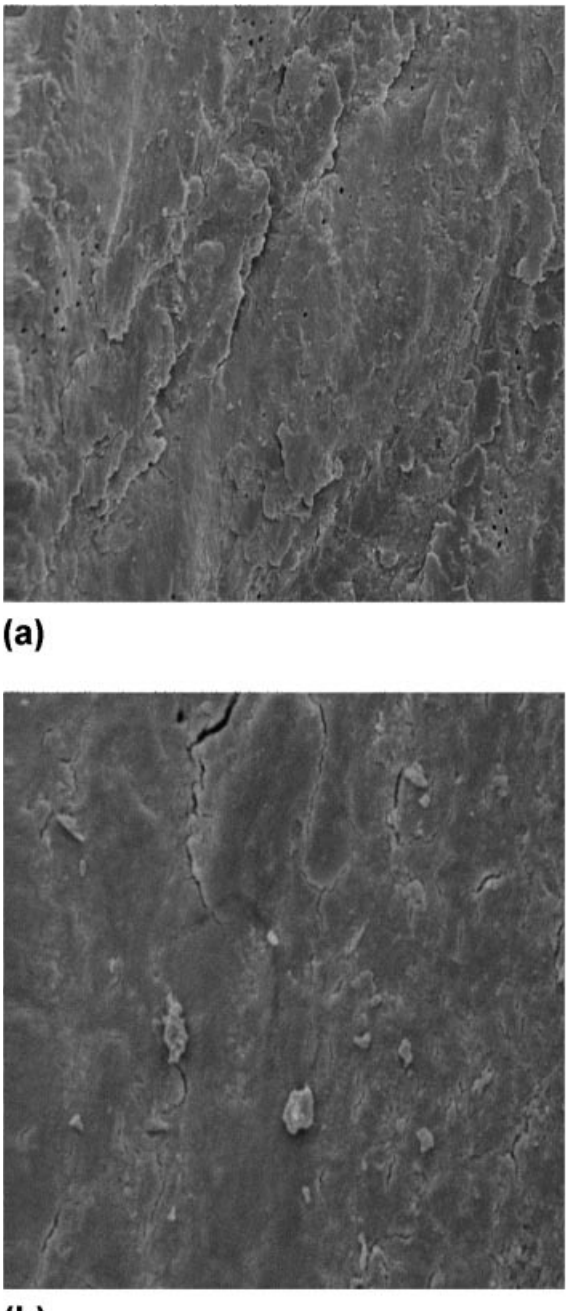


Figure 5 Apical part of root canal instrumented manually by Flexofiles and irrigated with 3.0% NaOCl. (a) Middle third of root canal wall (×2500) – small areas of partially removed smear layer interleaved with areas of thick flaky smear layer; canal wall free of loose debris. (b) Apical third of root canal wall (×2500): smooth texture of relatively thin smear layer with blocked dentine tubules (indicated by multiple cracks); limited amount of loose debris.

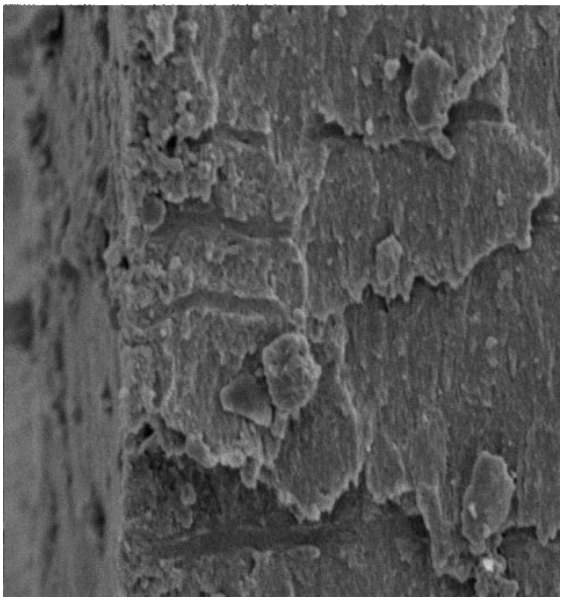
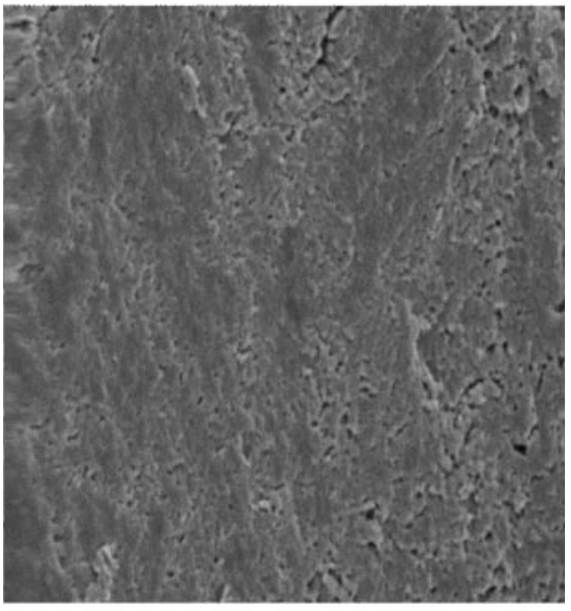


Figure 6 The marginal angle between the longitudinal fracture line and lumen of root canal instrumented manually by Flexofiles and irrigated with 3% NaOCl (×2500). Most dentine tubules are blocked with smear plugs.

Figure 7 Coronal third of root canal instrumented by Gates Glidden burs and irrigated with ANC solution (×2500). A smooth and slightly porous smear layer with fully or partially blocked tubules evenly distributed through the surface. A few small loose debris on root canal walls.

(a)



(b)

Figure 8 Apical part of root canal instrumented manually by Flexofiles and irrigated with ANC solution. (a) Middle third of canal wall (×2500) – large areas of thin smear layer with fully and partially blocked tubule orifices interleaved with a rough and porous thick smear layer. Scattered loose dent ine debris is also present. (b) Apical third of canal wall (×2500) – uniform smooth surface of thin smear layer with scattered open tubule orifices.

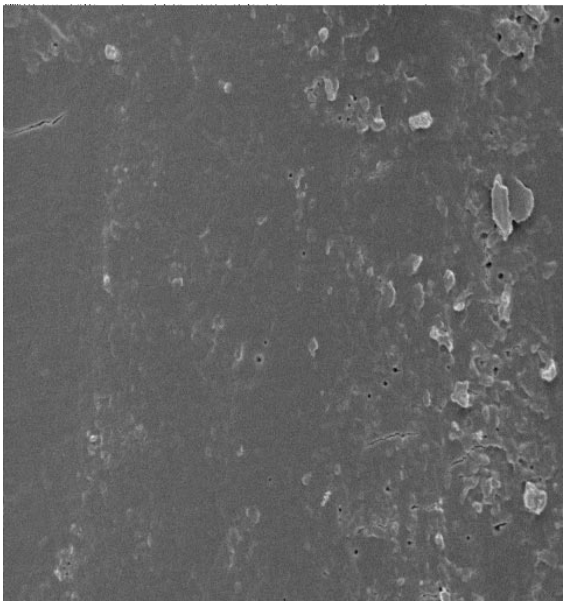


Figure 9 Coronal third of root canal instrumented by Gates Glidden burs and irrigated with alternate ANC and catholyte solutions (×800). Large areas of smooth smear layer with scattered open tubule orifices are present. Only a minor amount of small loose debris is present on root canal walls.

In the apical third the thickness of smear layer was more pronounced. Most specimens demonstrated a uniform smooth smear layer with scattered open tubule orifices. Loose debris were revealed in most specimens (Fig. 8B).

Alternate anolyte neutral cathodic (ANC) solution (300 mg L^{-1} active chlorine) and catholyte solution

SEM observation of specimens irrigated with alternate anolyte neutral cathodic (ANC) and catholyte solutions revealed a relatively uniform texture on the wall surface at all levels. Most samples demonstrated two types of surface appearance in both the coronal part instrumented with Gates Glidden burs and in the manually instrumented apical portion, namely, large areas of smooth surface with blocked and partly blocked dentine tubules interleaved with flaky smear layer. There was an obvious difference in these specimens compared to the other groups regarding the amount of loose debris; the amount of loosened debris was less in this group, particularly in the apical third of root canals (Figs 9 and 10).

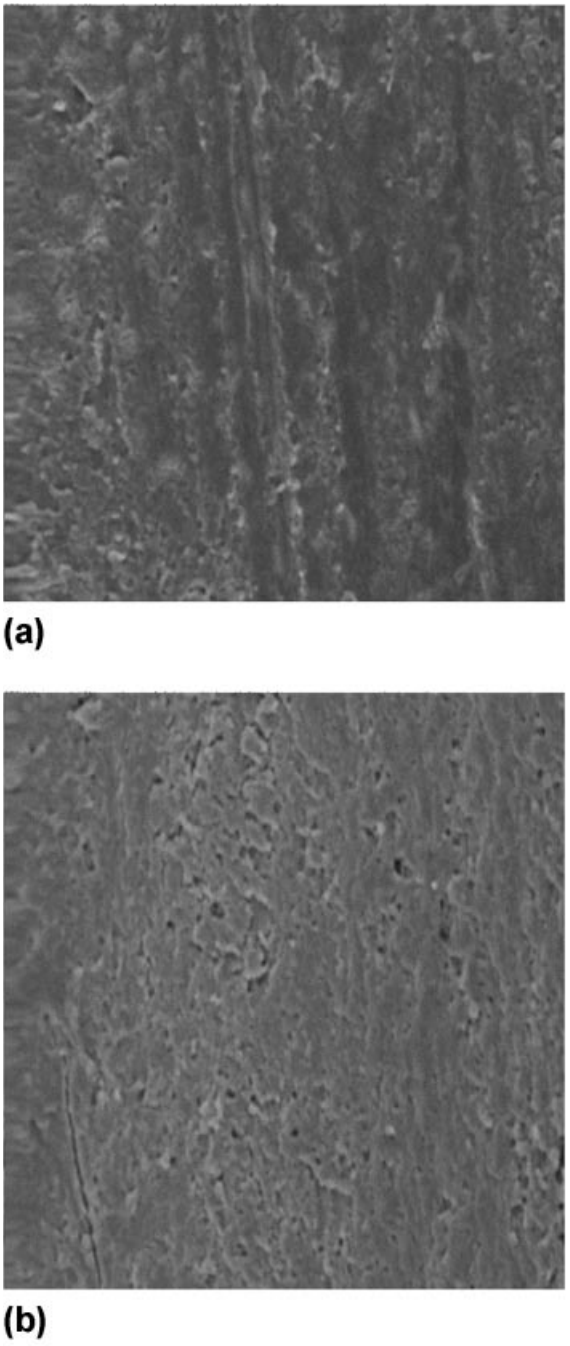


Figure 10 Apical part of root canal instrumented manually by Flexofiles and irrigated with ANC and catholyte solutions. (a) Middle third of canal wall ×2500) – relatively uniform smooth surface of a smear layer with fully and partially blocked tubules. (b) Apical third of canal wall (×2500) – uniform smooth surface of a thin smear layer with scattered open tubule orifices, free of loose debris.

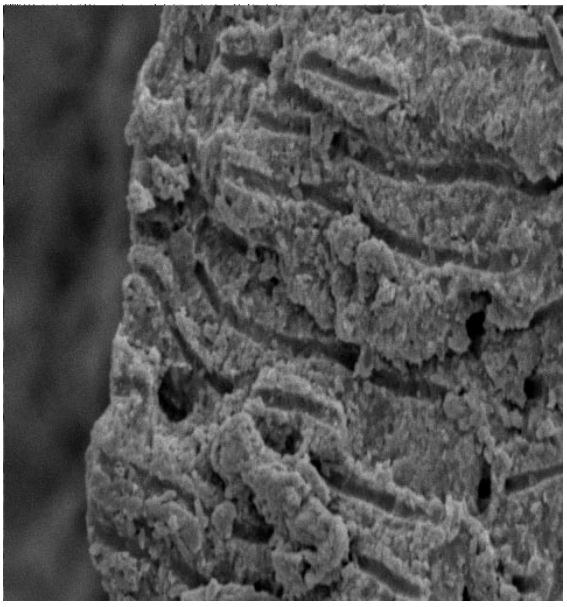


Figure 11 The marginal angle between longitudinal fracture line and lumen of root canal instrumented manually by Flexofiles and irrigated with ANC and catholyte (×2500). No signs of compressed dentine. A thin smear layer with dentine tubules directly open to the canal lumen.

SEM observation of the marginal angle between the longitudinal fracture line and root canal wall demonstrated the absence of compressed dentine and a thin smear layer with dentine tubules directly open to the canal lumen (Fig. 11).

Discussion

It has been demonstrated that anolyte neutral and anolyte neutral cathodic with concentrations of active chloride up to 300 mg L^{-1} are nontoxic when in contact with vital biological tissues (Shraev & Legchilo 1989, Shraev *et al.* 1993). The active chlorine concentrations of anolyte solution used in clinical practice are 50–150 mg L^{-1} for skin and mucous membrane treatment and 100–400 mg L^{-1} for cleaning, disinfecting, and sterilization (Melnikova *et al.* 1997). Catholyte provides necrotic tissue debridement but is safe for vital tissues (Prilutskii & Bakhir 1997).

Both types of ECA solutions (anolyte and catholyte) have been reported to be effective for the treatment of cutaneous and mucous membrane infections as well as for post-traumatic and postoperative suppurative complications, and purulent surgical diseases. ECA solutions are recommended for use in lesion and wound irrigation or dressing. Anolyte solution is reported to provide a pronounced microbiocidal effect in infected tissues and is indicated in an active purulent phase. Catholyte solution provides rapid elimination of necrotic tissues and is indicated for clinical application at the stage of wound healing. ECA solutions demonstrated more pronounced clinical effect and were associated with fewer incidences of allergic reactions compared to other antibacterial irrigants tested (Deviatov & Petrov 1992, Deviatov *et al.* 1993, Malakhov *et al.* 1994, Legchilo *et al.* 1996, Melnikova *et al.* 1997). Cleaning efficiency and safety for surfaces of dental instruments and equipment has been demonstrated in a number of studies (Sukhova *et al.* 1997, Marais & Brozel 1999).

The experience of Oxidative Potential Water application for irrigation of root canals has been reported (Hata *et al.* 1996). However, Hata and coworkers studied the effect of acidic anolyte solutions. The anolyte neutral cathodic solution (ANC), described more recently and used in the present study, provides an increased antiseptic effect and an enhanced cleaning ability at lower concentrations of active chlorine compared to the acidic anolyte and anolyte neutral solutions because of its higher concentration of peroxides (Bakhir *et al.* 1999). Taking that into account, investigation of its potential as a root canal irrigant seems sensible.

In order to evaluate the canal cleaning effectiveness of electrochemically activated solutions the experimental irrigants were compared with the negative and positive test groups. To avoid the potentially confounding influence of root canal instrumentation a standard regimen was adopted for all canals; this was limited to manual stainless steel instruments (Flexofiles, Dentsply Maillefer). Many authors have demonstrated that manual instrumentation combined with 3% NaOCl irrigation is ineffective in removing the smear layer (Cheung & Stock 1993).

Evaluation of the presence of loose debris demonstrated that distilled water was the least efficient irrigant with residual debris remaining throughout the length of the root canals. The quality of debridement was better in the coronal and middle parts of canal walls where only scattered debris was noted in contrast to the apical part that contained numerous debris particles. This observation confirms the previously published results (Baumgartner & Mader 1987, Walker & del Rio 1991).

All chemically active irrigants demonstrated improved cleaning potential compared to distilled water. The degree of loose debris elimination was similar for NaOCl (group 2) and the ANC solution (group 3). The combination of ANC and catholyte (group 4) resulted in improved cleaning with only minor amounts of debris remaining, particularly in the apical third of canals.

The evaluation of smear layer demonstrated that none of the irrigants were effective in its removal. However, the smear layer was disrupted by chemically active irrigants compared to distilled water. Water irrigation combined with manual instrumentation resulted in a continuous and firm smear layer that covered compressed low-mineralized predentine compacted against the dentine wall. NaOCl and ECA solutions affected the surface and thickness of smear layer. Compared to NaOCl the ECA solutions (groups 3 and 4) left a thinner smear layer with a smoother and more even surface. The texture of the canal surfaces treated with ECA solutions was relatively uniform in the various regions of the root canal and did not seem to be influenced by the method of instrumentation, that is, manual or mechanical.

Irrigation with NaOCl or ECA solutions enhanced the opening of dentine tubules. It is important to note that irrigation with NaOCl resulted in open tubules predominantly in the coronal and middle thirds of root canals; no signs of tubule orifices were revealed in the apical third of canals. Irrigating with anolyte neutral cathodic (group 3) as well as with alternate ANC and catholyte (group 4) resulted in more numerous open dentine tubules in the apical as well as in the coronal regions.

In most specimens irrigation with NaOCl resulted in local removal of smear layer in limited areas. These areas probably were inaccessible for direct instrumentation with files. It is well known that NaOCl dissolves the organic component of the smear layer (Haikel *et al*. 1994). There was evidence that in uninstrumented areas of the root canal where no smear layer had been formed NaOCl solution removed the predentine by its protein-dissolving effect, meanwhile in the areas of thick smear layer with high mineral content this effect was not obvious (Baumgartner & Cuenin 1992). In specimens treated with ANC and catholyte (group 4) open tubule orifices were scattered evenly throughout the canal.

Conclusion

The results suggest irrigation with electrochemically activated solutions provide efficient cleaning of root canal walls and may be an alternative to NaOCl in conventional root canal treatment. Further investigations of ECA solutions are warranted.

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