

REVIEW

The smear layer in endodontics – a review**D. R. Violich¹ & N. P. Chandler²**¹Private Endodontic Practice, Tauranga, New Zealand; and ²Sir John Walsh Research Institute, School of Dentistry, University of Otago, Dunedin, New Zealand**Abstract****Violich DR, Chandler NP.** The smear layer in endodontics – a review. *International Endodontic Journal*, **43**, 2–15, 2010.

Root canal instrumentation produces a layer of organic and inorganic material called the smear layer that may also contain bacteria and their by-products. It can prevent the penetration of intracanal medicaments into dentinal tubules and influence the adaptation of filling materials to canal walls. This article provides an overview of the smear layer, focusing on its relevance to endodontics. The PubMed database was used initially; the reference list for smear layer featured 1277 articles, and for both smear layer dentine and smear layer root canal revealed 1455 publications. Smear layer endodontics disclosed 408 papers. A forward search was undertaken on selected articles and using some author names. Potentially relevant material was also sought in contemporary endodontic

texts, whilst older books revealed historic information and primary research not found electronically, such that this paper does not represent a 'classical' review. Data obtained suggests that smear layer removal should enhance canal disinfection. Current methods of smear removal include chemical, ultrasonic and laser techniques – none of which are totally effective throughout the length of all canals or are universally accepted. If smear is to be removed, the method of choice seems to be the alternate use of ethylenediaminetetraacetic acid and sodium hypochlorite solutions. Conflict remains regarding the removal of the smear layer before filling root canals, with investigations required to determine the role of the smear layer in the outcomes of root canal treatment.

Keywords: dentine, ethylenediaminetetraacetic acid, endodontic treatment, smear layer.*Received 20 June 2007; accepted 21 July 2009***Introduction**

Whenever dentine is cut using hand or rotary instruments, the mineralized tissues are not shredded or cleaved but shattered to produce considerable quantities of debris. Much of this, made up of very small particles of mineralized collagen matrix, is spread over the surface to form what is called the smear layer. Identification of the smear layer was made possible using the electron microprobe with scanning electron microscope (SEM) attachment, and

first reported by Eick *et al.* (1970). These workers showed that the smear layer was made of particles ranging in size from less than 0.5–15 μm . Scanning electron microscope studies of cavity preparations by Brännström & Johnson (1974) demonstrated a thin layer of grinding debris. They estimated it to be 2–5 μm thick, extending a few micrometres into the dentinal tubules.

The smear layer in a cavity and in the root canal may not be directly comparable. Not only are the tools for dentine preparation different in coronal cavities, but in the root canal the dentinal tubule numbers show greater variation and there are likely to be more soft tissue remnants present. The first researchers to describe the smear layer on the surface of instrumented root canals were McComb & Smith (1975). They

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suggested that the smear layer consisted not only of dentine as in the coronal smear layer, but also the remnants of odontoblastic processes, pulp tissue and bacteria. Lester & Boyde (1977) described the smear layer as 'organic matter trapped within translocated inorganic dentine'. As it was not removed by sodium hypochlorite irrigation, they concluded that it was primarily composed of inorganic dentine. Goldman *et al.* (1981) estimated the smear thickness at 1 μm and agreed with previous investigators that it was largely inorganic in composition. They noted its presence along instrumented canal surfaces. Mader *et al.* (1984) reported that the smear layer thickness was generally 1–2 μm . Cameron (1983) and Mader *et al.* (1984) discussed the smear material in two parts: first, superficial smear layer (Fig. 1) and second, the material packed into the dentinal tubules. Packing of smear debris was present in the tubules to a depth of 40 μm . Brännström & Johnson (1974) and Mader *et al.* (1984) concluded that the tubular packing phenomenon was due to the action of burs and instruments. Components of the smear layer can be forced into the dentinal tubules to varying distances (Moodnik *et al.* 1976, Brännström *et al.* 1980, Cengiz *et al.* 1990) to form smear plugs (Fig. 2). However, Cengiz *et al.* (1990) proposed that the penetration of smear material into dentinal tubules could also be caused by capillary action as a result of adhesive forces between the dentinal tubules and the material. This hypothesis of capillary action may explain the packing phenomenon observed by Aktener *et al.* (1989), who showed that the penetration could increase up to 110 μm when using

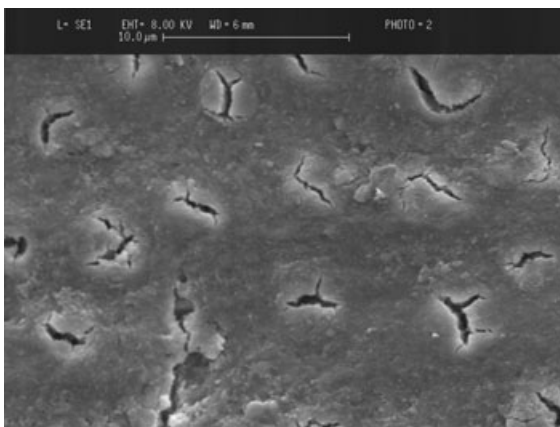


Figure 1 Scanning electron micrograph of smeared surface of dentine. The crack shapes are processing artefacts overlying dentinal tubules.

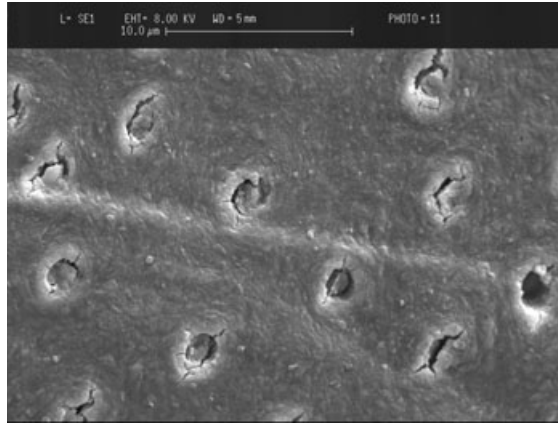


Figure 2 Scanning electron micrograph of dentine surface showing smear plugs occluding tubules. The surface has been treated for 60 s with Tubulicid Blue Label (Dental Therapeutics AB, Nacka, Sweden).

surface-active reagents in the canal during endodontic instrumentation. The thickness may also depend on the type and sharpness of the cutting instruments and whether the dentine is dry or wet when cut (Barnes 1974, Gilboe *et al.* 1980, Cameron 1988). In the early stages of instrumentation, the smear layer on the walls of canals can have a relatively high organic content because of necrotic and/or viable pulp tissue in the root canal (Cameron 1988). Increased centrifugal forces resulting from the movement and the proximity of the instrument to the dentine wall formed a thicker layer which was more resistant to removal with chelating agents (Jodaikin & Austin 1981). The amount produced during motorized preparation, as with Gates-Glidden or post drills, has been reported as greater in volume than that produced by hand filing (Czonstowski *et al.* 1990). However, McComb & Smith (1975) observed under SEM that instrumentation with K-reamers, K-files and Giromatic reciprocating files created similar surfaces. Additional work has shown that the smear layer contains organic and inorganic substances that include fragments of odontoblastic processes, microorganisms and necrotic materials (Pashley 1992). The generation of a smear layer is almost inevitable during root canal instrumentation. Whilst a noninstrumentation technique has been described for canal preparation without smear formation, efforts rather focus on methods for its removal, such as chemical means and methods such as ultrasound and hydrodynamic disinfection for its disruption. Root canal preparation without the creation of a smear

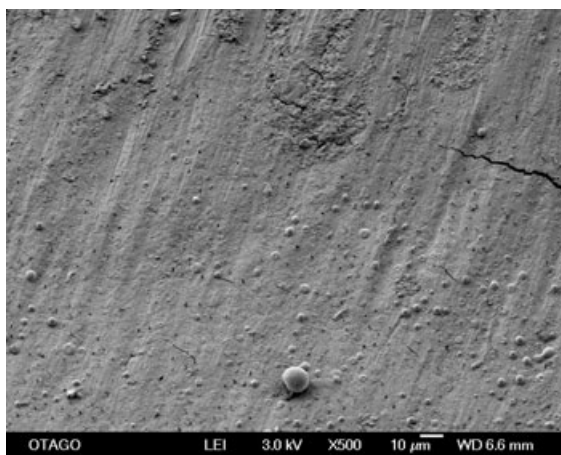


Figure 3 Scanning electron micrograph of dentine surface with typical amorphous smear layer with granular appearance and moderate debris present (courtesy of Dr Artika Soma).

layer may be possible. A noninstrumental hydrodynamic technique may have future potential (Lussi *et al.* 1993), and sonically driven polymer instruments with tips of variable diameter are reported to disrupt the smear layer in a technique called hydrodynamic disinfection (Ruddle 2007).

When viewed under the SEM, the smear layer often has an amorphous irregular and granular appearance (Brännström *et al.* 1980, Yamada *et al.* 1983, Pashley *et al.* 1988) (Fig. 3). The appearance is thought to be formed by translocating and burnishing the superficial components of the dentine walls during treatment (Baumgartner & Mader 1987).

The significance of the smear layer

Root canal treatment usually involves the chemomechanical removal of bacteria and infected dentine from within the root canals. The process is often followed by an intracanal dressing and a root filling. Amongst important factors affecting the prognosis of root canal treatment is the seal created by the filling against the walls of the canal. Considerable effort has been made to understand the effect of the smear layer on the apical and coronal seal (Madison & Krell 1984, Goldberg *et al.* 1985, 1995, Evans & Simon 1986, Kennedy *et al.* 1986, Cergneux *et al.* 1987, Saunders & Saunders 1992, 1994, Gençoğlu *et al.* 1993a, Karagöz-Küçükay & Bayirli 1994, Tidswell *et al.* 1994, Lloyd *et al.* 1995, Behrend *et al.* 1996, Chailertvanitkul *et al.* 1996,

Vassiliadis *et al.* 1996, Taylor *et al.* 1997, Timpawat & Sripanaratanakul 1998, Economides *et al.* 1999, 2004, von Fraunhofer *et al.* 2000, Froés *et al.* 2000, Goya *et al.* 2000, Timpawat *et al.* 2001, Clark-Holke *et al.* 2003, Cobankara *et al.* 2004, Park *et al.* 2004).

Workers have reached different conclusions, with current knowledge of interactions between the smear layer and factors such as filling technique and sealer type being limited. In addition, the methodology of studies, the type and site of leakage tests, and the sample size should be taken into account and consideration given to these variables before conclusions are reached (Shahravan *et al.* 2007).

Some authors suggest that maintaining the smear layer may block the dentinal tubules and limit bacterial or toxin penetration by altering dentinal permeability (Michelich *et al.* 1980, Pashley *et al.* 1981, Safavi *et al.* 1990). Others believe that the smear layer, being a loosely adherent structure, should be completely removed from the surface of the root canal wall because it can harbour bacteria and provide an avenue for leakage (Mader *et al.* 1984, Cameron 1987a, Meryon & Brook 1990). It may also limit the effective disinfection of dentinal tubules by preventing sodium hypochlorite, calcium hydroxide and other intracanal medicaments from penetrating the dentinal tubules.

Should the smear layer be removed?

The question of keeping or removing the smear layer remains controversial (Drake *et al.* 1994, Shahravan *et al.* 2007). Some investigations have focussed on its removal (Garberoglio & Brännström 1976, Outhwaite *et al.* 1976, Pashley 1985), whilst others have considered its effects on apical and coronal microleakage (Madison & Krell 1984, Goldberg *et al.* 1995, Chailertvanitkul *et al.* 1996), bacterial penetration of the tubules (Pashley 1984, Williams & Goldman 1985, Meryon & Brook 1990) and the adaptation of root canal materials (White *et al.* 1987, Gençoğlu *et al.* 1993a, Gutmann 1993). In support of its removal are:

1. It has an unpredictable thickness and volume, because a great portion of it consists of water (Cergneux *et al.* 1987).
2. It contains bacteria, their by-products and necrotic tissue (McComb & Smith 1975, Goldberg & Abramovich 1977, Wayman *et al.* 1979, Cunningham & Martin 1982, Yamada *et al.* 1983). Bacteria may survive and multiply (Brännström & Nyborg 1973) and can proliferate into the dentinal tubules (Olgart *et al.* 1974, Akpata & Blechman 1982, Williams &

Goldman 1985, Meryon *et al.* 1986, Meryon & Brook 1990), which may serve as a reservoir of microbial irritants (Pashley 1984).

3. It may act as a substrate for bacteria, allowing their deeper penetration in the dentinal tubules (George *et al.* 2005).

4. It may limit the optimum penetration of disinfecting agents (McComb & Smith 1975, Outhwaite *et al.* 1976, Goldberg & Abramovich 1977, Wayman *et al.* 1979, Yamada *et al.* 1983). Bacteria may be found deep within dentinal tubules (Byström & Sundqvist 1981, 1983, 1985) and smear layer may block the effects of disinfectants in them (Goldberg & Abramovich 1977, Wayman *et al.* 1979, Yamada *et al.* 1983, Baumgartner & Mader 1987). Haapasalo & Ørstavik (1987) found that in the absence of smear layer, liquid camphorated monochlorophenol disinfected the dentinal tubules rapidly and completely, but calcium hydroxide failed to eliminate *Enterococcus faecalis* even after 7 days of incubation. A subsequent study concluded that the smear layer delayed but did not abolish the action of the disinfectant (Ørstavik & Haapasalo 1990). Brännström (1984) had previously stated that following the removal of the smear layer, bacteria in the dentinal tubules can easily be destroyed.

5. It can act as a barrier between filling materials and the canal wall and therefore compromise the formation of a satisfactory seal (Lester & Boyde 1977, White *et al.* 1984, Cergneux *et al.* 1987, Czonstkowsky *et al.* 1990, Foster *et al.* 1993, Yang & Bae 2002). Lester & Boyde (1977) found that zinc oxide – eugenol based root canal sealers failed to enter dentinal tubules in the presence of smear. In two consecutive studies, White *et al.* observed that plastic filling materials and sealers penetrated dentinal tubules after removal of smear layer (White *et al.* 1984, 1987). Okşan *et al.* (1993) also found that smear prevented the penetration of sealers into dentinal tubules, whilst no penetration of sealer was observed in control groups. Penetration in their smear-free groups ranged from 40 to 60 µm. It may be concluded that such tubular penetration increases the interface between the filling and the dentinal structures, which may improve the ability of a filling material to prevent leakage (White *et al.* 1984). If the aim is maximum penetration into the dentinal tubules to prevent microleakage, root canal filling materials should be applied to a surface free of smear and either a low surface activity or, alternatively, an adequate surface-active reagent must be added to them (Aktener *et al.* 1989). However, there are no reports of a correlation between microleakage and penetration of

filling materials into dentinal tubules, whilst the basis of leakage studies remains questionable. Pashley *et al.* (1989) observed an extensive network of microchannels around restorations that had been placed in cavities with smear layer. The thickness of these channels was 1–10 µm. Smear layer may thus present a passage for substances to leak around or through its particles at the interface between the filling material and the tooth structure. Pashley & Depew (1986) reported that, when experimenting with class I cavities, microleakage decreased after the removal of smear layer, but dentinal permeability increased. Saunders & Saunders (1992) concluded that coronal leakage of root canal fillings was less in smear-free groups than those with a smear layer.

6. It is a loosely adherent structure and a potential avenue for leakage and bacterial contaminant passage between the root canal filling and the dentinal walls (Mader *et al.* 1984, Cameron 1987b, Meryon & Brook 1990). Its removal would facilitate canal filling (McComb & Smith 1975, Goldman *et al.* 1981, Cameron 1983).

Conversely, some investigators believe in retaining the smear layer during canal preparation, because it can block the dentinal tubules, preventing the exchange of bacteria and other irritants by altering permeability (Michelich *et al.* 1980, Pashley *et al.* 1981, Safavi *et al.* 1990, Drake *et al.* 1994, Galvan *et al.* 1994). The smear layer serves as a barrier to prevent bacterial migration into the dentinal tubules (Drake *et al.* 1994, Galvan *et al.* 1994, Love *et al.* 1996, Perez *et al.* 1996). Pashley (1985) suggested that if the canals were inadequately disinfected, or if bacterial contamination occurred after canal preparation, the presence of a smear layer might stop bacterial invasion of the dentinal tubules. Bacteria remaining after canal preparation are sealed into the tubules by the smear layer and subsequent filling materials. Some studies provide evidence to support the hypothesis that the smear layer inhibits bacterial penetration (Pashley *et al.* 1981, Safavi *et al.* 1989). A major limitation is that the experiments were undertaken with dentine discs or root cross-sections, models with little relevance in terms of simulating the clinical conditions of root canal treatment. Drake *et al.* (1994) developed a more clinically relevant model to determine the effect of the presence or absence of the smear layer on bacterial colonization of root canals.

Williams & Goldman (1985) reported that the smear layer was not a complete barrier and could only delay bacterial penetration. In their experiment, using the

motile, swarming bacterium *Proteus vulgaris*, the smear layer delayed the passage of the organisms through the tubules. Madison & Krell (1984) using ethylenediaminetetraacetic acid (EDTA) solution in a dye penetration study found that the smear layer made no difference to leakage. Goldberg *et al.* (1995) studied the sealing ability of Ketac Endo and Tubliseal in an India ink study with and without smear layer and found no difference. Chailertvanitkul *et al.* (1996) found no difference in leakage with or without smear layer, however the time period was short. When the smear layer is not removed, the durability of the apical seal should be evaluated over a long period. Since the smear layer is nonhomogenous and may potentially be dislodged from the underlying tubules (Mader *et al.* 1984), it may slowly disintegrate, dissolving around a leaking filling material to leave a void between the canal wall and sealer. Meryon & Brook (1990) found the presence of smear layer had no effect on the ability of three oral bacteria to penetrate dentine discs. All were able to digest the layer, possibly stimulated by the nutrient-rich medium below the discs.

The adaptation of root canal materials to canal walls has been studied. White *et al.* (1987) found that pHEMA, silicone and Roth 801 and AH26 sealers extended into tubules consistently when smear layer was removed. Gençoğlu *et al.* (1993b) found removing the smear layer enhanced the adaptation of gutta-percha in both cold laterally compacted and thermoplastic root fillings without sealer. Gutmann (1993) also showed that after removing the smear layer, thermoplastic gutta-percha adapted with or without sealer.

A systematic review and meta-analysis by Shahrvan *et al.* (2007) set out to determine whether smear layer removal reduced leakage of root filled teeth *ex vivo*. Using 26 eligible papers with 65 comparisons, 54% of the comparisons reported no significant difference, 41% reported in favour of removing the smear layer and 5% reported a difference in favour of keeping it. They concluded that smear layer removal improved the fluid-tight seal of the root canal system, whereas other factors such as filling technique or the type of sealer did not produce significant effects.

Urethane dimethacrylate (UDMA) based root canal sealers have been introduced. Their aim is to provide a better bond to allow less microleakage and increase the fracture resistance of root filled teeth through the creation of monoblocks, when a core material such as Resilon replaces gutta-percha. Whilst some studies indicate that smear layer removal leads to higher

tubule penetration, increased sealer to dentine bond strength and enhanced fluid-tight seal, a recent report concluded that smear layer removal did not necessarily equate to improved resistance to bacterial penetration along these and older types of sealers (Saleh *et al.* 2008).

Methods to remove the smear layer

Chemical removal

The quantity of smear layer removed by a material is related to its pH and the time of exposure (Morgan & Baumgartner 1997). A number of chemicals have been investigated as irrigants to remove the smear layer. According to Kaufman & Greenberg (1986), a working solution is the one which is used to clean the canal, and an irrigation solution the one which is essential to remove the debris and smear layer created by the instrumentation process. Chlorhexidine, whilst popular as an irrigant and having a long lasting antibacterial effect through adherence to dentine, does not dissolve organic material or remove the smear layer.

Sodium hypochlorite

The ability of NaOCl to dissolve organic tissues is well-known (Rubin *et al.* 1979, Wayman *et al.* 1979, Goldman *et al.* 1982) and increases with rising temperature (Moorer & Wesselink 1982). However, its capacity to remove smear layer from the instrumented root canal walls has been found to be lacking. The conclusion reached by many authors is that the use of NaOCl during or after instrumentation produces superficially clean canal walls with the smear layer present (Baker *et al.* 1975, Goldman *et al.* 1981, Berg *et al.* 1986, Baumgartner & Mader 1987).

Chelating agents

Smear layer components include very small particles with a large surface : mass ratio, which makes them soluble in acids (Pashley 1992). The most common chelating solutions are based on EDTA which reacts with the calcium ions in dentine and forms soluble calcium chelates (Fig. 4). It has been reported that EDTA decalcified dentine to a depth of 20–30 µm in 5 min (von der Fehr & Nygaard-Östby 1963); however, Fraser (1974) stated that the chelating effect was almost negligible in the apical third of root canals.

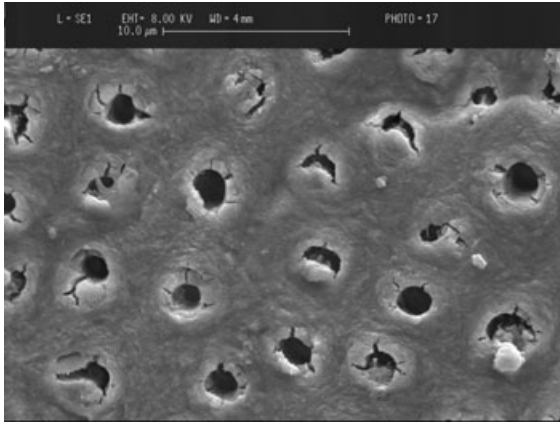


Figure 4 Scanning electron micrograph of dentine following 60 s exposure to 18% ethylenediaminetetraacetic acid solution (Ultradent Products Inc., South Jordan, UT, USA).

Different formulations of EDTA have been used as root canal irrigants. In a combination, urea peroxide is added to encourage debris to float out of the root canal (Stewart *et al.* 1969). This product (RC-Prep, Premier Dental Products, Plymouth Meeting, PA, USA) also includes a wax that left a residue on the root canal walls despite further instrumentation and irrigation and which may compromise the ability to obtain a hermetic seal (Biesterfeld & Taintor 1980). Many studies have shown that paste-type chelating agents, whilst having a lubricating effect, do not remove the smear layer effectively when compared to liquid EDTA. A recent experiment examining the addition of two surfactants to liquid EDTA did not result in better smear layer removal (Lui *et al.* 2007).

A quaternary ammonium bromide (cetrimide) has been added to EDTA solutions to reduce surface tension and increase penetrability of the solution (von der Fehr & Nygaard-Östby 1963). McComb & Smith (1975) reported that when this combination (REDTA) was used during instrumentation, there was no smear layer remaining except in the apical part of the canal. After using REDTA *in vivo*, it was shown that the root canal surfaces were uniformly occupied by patent dentinal tubules with very little superficial debris (McComb *et al.* 1976). When used during and after instrumentation, it was possible to still see remnants of odontoblastic processes within the tubules even though there was no smear layer present (Goldman *et al.* 1981). Goldberg & Abramovich (1977) observed that the circumpulpal surface had a smooth structure and that the dentinal tubules had a regular circular appearance with the use

of EDTAC (EDTA and cetavlon). The optimal working time of EDTAC was suggested to be 15 min in the root canal and no further chelating action could be expected after this (Goldberg & Spielberg 1982). This study also showed that REDTA was the most efficient irrigating solution for removing smear layer. In a study using a combination of 0.2% EDTA and a surface-active antibacterial solution, Brännström *et al.* (1980) observed that this mixture removed most of the smear layer without opening many dentinal tubules or removing peritubular dentine. Bis-dequalinium-acetate (BDA), a dequalinium compound and an oxine derivative has been shown to remove the smear layer throughout the canal, even in the apical third (Kaufman *et al.* 1978, Kaufman 1981). BDA is well tolerated by periodontal tissues and has a low surface tension allowing good penetration. It is considered less toxic than NaOCl and can be used as a root canal dressing. A commercial form of BDA called Solvidont (De Trey, A.G., Zurich, Switzerland) was available in the 1980s and its use as an alternative to NaOCl was supported experimentally (Kaufman 1983a,b, Chandler & Lilley 1987, Lilley *et al.* 1988, Mohd Sulong 1989). Salvizol (Ravens GmbH, Konstanz, Germany) is a commercial brand of 0.5% BDA and possesses the combined actions of chelation and organic debridement. Kaufman *et al.* (1978) reported that Salvizol had better cleaning properties than EDTAC. When comparing Salvizol with 5.25% NaOCl, both were found comparable in their ability to remove organic debris, but only Salvizol opened dentinal tubules (Kaufman & Greenberg 1986). Berg *et al.* (1986) found that Salvizol was less effective at opening dentinal tubules than REDTA.

Çalt & Serper (2000) compared the effects of ethylene glycol-bis (β-aminoethyl ether)-*N,N,N',N'*-tetraacetic acid (EGTA) with EDTA. The smear layer was completely removed by EDTA, but it caused erosion of the peritubular and intertubular dentine, whilst EGTA was not as effective in the apical third of root canals. EGTA is reported to bind calcium more specifically (Schmid & Reilly 1957).

Tetracyclines (including tetracycline hydrochloride, minocycline and doxycycline) are antibiotics effective against a wide range of microorganisms. Tetracyclines have unique properties in addition to their antimicrobial aspect. They have low pH in concentrated solution, and because of this can act as a calcium chelator and cause enamel and root surface demineralization (Bjorvatn 1982). The surface demineralization of dentine is comparable with that of citric acid (Wikesjö *et al.* 1986). Barkhordar *et al.* (1997) reported that doxycy-

cline hydrochloride (100 mg mL⁻¹) was effective in removing the smear layer from the surface of instrumented canals and root-end cavity preparations. They speculated that a reservoir of active antibacterial agents might remain, because doxycycline readily attaches to dentine and can be subsequently released (Baker *et al.* 1983, Wikesjö *et al.* 1986). Haznedaroglu & Ersev (2001) showed that 1% tetracycline hydrochloride or 50% citric acid can be used to remove the smear layer from surfaces of root canals. Although they reported no difference between the two groups, it appeared that the tetracycline demineralized less peritubular dentine than the citric acid.

In an effort to produce an irrigant capable of both removing the smear layer and disinfecting the root canal system, Torabinejad *et al.* (2003) developed a new irrigating solution containing a mixture of a tetracycline isomer, an acid, and a detergent (MTAD). Their work concluded MTAD to be an effective solution for the removal of the smear layer. It does not significantly change the structure of the dentinal tubules when the canals are irrigated with sodium hypochlorite and followed with a final rinse of MTAD. This irrigant demineralizes dentine faster than 17% EDTA (De-Deus *et al.* 2007) and bacterial penetration into filled canals is similar with both solutions (Ghodusi *et al.* 2007).

Organic acids

The effectiveness of citric acid as a root canal irrigant has been demonstrated (Loel 1975, Tidmarsh 1978) and confirmed to be more effective than NaOCl alone in removing the smear layer (Baumgartner *et al.* 1984). Citric acid removed smear layer better than polyacrylic acid, lactic acid and phosphoric acid but not EDTA (Meryon *et al.* 1987). Wayman *et al.* (1979) showed that canal walls treated with 10%, 25% and 50% citric acid solution were generally free of the smeared appearance, but they had the best results in removing smear layer with sequential use of 10% citric acid solution and 2.5% NaOCl solution, then again followed by a 10% solution of citric acid. However, Yamada *et al.* (1983) observed that the 25% citric acid–NaOCl group was not as effective as a 17% EDTA–NaOCl combination. To its detriment, citric acid left precipitated crystals in the root canal which might be disadvantageous to the root canal filling. With 50% lactic acid, the canal walls were generally clean, but with openings of dentinal tubules that did not appear to be completely patent (Wayman *et al.* 1979). Bitter

(1989) introduced 25% tannic acid solution as a root canal irrigant and cleanser. Canal walls irrigated with this solution appeared significantly cleaner and smoother than walls treated with a combination of hydrogen peroxide and NaOCl, and the smear layer was removed. Sabbak & Hassanin (1998) refuted these findings and explained that tannic acid increased the cross-linking of exposed collagen with the smear layer and within the matrix of the underlying dentine, therefore increasing organic cohesion to the tubules.

McComb & Smith (1975) compared the efficacy of 20% polyacrylic acid with REDTA and found that it was no better than REDTA in removing or preventing the build up of smear layer, thought to be as a result of its higher viscosity. McComb *et al.* (1976) also used 5% and 10% polyacrylic acid as an irrigant and observed that it could remove smear layer in accessible regions. Polyacrylic acid (Durelon liquid and Fuji II liquid) at 40% has been reported to be very effective, and because of its potency users should not exceed a 30 s application (Berry *et al.* 1987).

Sodium hypochlorite and EDTA

When irrigating a root canal the purpose is twofold: to remove the organic component, the debris originating from pulp tissue and microorganisms, and the mostly inorganic component, the smear layer. As there is no single solution which has the ability to dissolve organic tissues and to demineralize the smear layer, the sequential use of organic and inorganic solvents has been recommended (Koskinen *et al.* 1980, Yamada *et al.* 1983, Baumgartner *et al.* 1984). Numerous authors have agreed that the removal of smear layer as well as soft tissue and debris can be achieved by the alternate use of EDTA and NaOCl (Yamada *et al.* 1983, White *et al.* 1984, Baumgartner & Mader 1987, Cengiz *et al.* 1990). Goldman *et al.* (1982) examined the effect of various combinations of EDTA and NaOCl, and the most effective final rinse was 10 mL of 17% EDTA followed by 10 mL of 5.25% NaOCl, a finding confirmed by Yamada *et al.* (1983). Used in combination with EDTA, NaOCl is inactivated with the EDTA remaining functional for several minutes.

Ultrasonic smear removal

Following the introduction of dental ultrasonic devices in the 1950s, ultrasound was investigated in endodontics (Martin *et al.* 1980, Cunningham & Martin 1982, Cunningham *et al.* 1982). A continuous flow of

NaOCl activated by an ultrasonic delivery system was used for the preparation and irrigation of canals. Smear-free canal surfaces were observed using this method (Cameron 1983, 1987a,b, Griffiths & Stock 1986, Alaçam 1987). Whilst concentrations of 2–4% sodium hypochlorite in combination with ultrasonic energy were able to remove smear layer, lower concentrations of the solutions were unsatisfactory (Cameron 1988). However, Ahmad *et al.* (1987a) claimed that their technique of modified ultrasonic instrumentation using 1% NaOCl removed the debris and smear layer more effectively than the technique recommended by Martin & Cunningham (1983). The apical region of the canals showed less debris and smear layer than the coronal aspects, depending on acoustic streaming, which was more intense in magnitude and velocity at the apical regions of the file. Cameron (1983) also compared the effect of different ultrasonic irrigation periods on removing smear layer and found that a 3- and 5-min irrigation produced smear-free canal walls, whilst a 1-min irrigation was ineffective. In contrast to these results, other investigators found ultrasonic preparation unable to remove smear layer (Cymerman *et al.* 1983, Baker *et al.* 1988, Goldberg *et al.* 1988).

Researchers who found the cleaning effects of ultrasonics beneficial used the technique only for the final irrigation of root canal after completion of hand instrumentation (Ahmad *et al.* 1987a, Alaçam 1987, Cameron 1988). This is given the term passive ultrasonic irrigation and has been the subject of a recent review (van der Sluis *et al.* 2007). Ahmad *et al.* (1987a,b) claimed that direct physical contact of the file with the canal walls throughout instrumentation reduced acoustic streaming. Acoustic streaming is maximized when the tips of the smaller instruments vibrate freely in a solution. Lumley *et al.* (1992) recommended that only size 15 files be used to maximize microstreaming for the removal of debris. Prati *et al.* (1994) also achieved smear layer removal with ultrasonics. Walker & del Rio (1989, 1991) showed no significant difference between tap water and sodium hypochlorite when used with ultrasonics, but they reported that neither solution was effective at any level in the canal to remove the smear layer ultrasonically. Baumgartner & Cuenin (1992) also observed that ultrasonically energized NaOCl, even at full strength, did not remove the smear layer from root canal walls. Guerisoli *et al.* (2002) evaluated the use of ultrasonics to remove the smear layer and found it necessary to use 15% EDTAC with either distilled water

or 1% sodium hypochlorite to achieve the desired result.

Laser removal

Lasers can be used to vaporize tissues in the main canal, remove the smear layer and eliminate residual tissue in the apical portion of root canals (Takeda *et al.* 1998a,b, 1999). The effectiveness of lasers depends on many factors, including the power level, the duration of exposure, the absorption of light in the tissues, the geometry of the root canal and the tip-to-target distance (Dederich *et al.* 1984, Önal *et al.* 1993, Tewfik *et al.* 1993, Moshonov *et al.* 1995).

Dederich *et al.* (1984) and Tewfik *et al.* (1993) used variants of the neodymium–yttrium–aluminium–garnet (Nd:YAG) laser and reported a range of findings from no change or disruption of the smear layer to actual melting and recrystallization of the dentine. This pattern of dentine disruption was observed in other studies with various lasers, including the carbon dioxide laser (Önal *et al.* 1993), the argon fluoride excimer laser (Stabholz *et al.* 1993), and the argon laser (Moshonov *et al.* 1995, Harashima *et al.* 1998). Takeda *et al.* (1998a,b, 1999) using the erbium–yttrium–aluminium–garnet (Er:YAG) laser, demonstrated optimal removal of the smear layer without melting, charring or recrystallization associated with other laser types. Kimura *et al.* (2002) also demonstrated the removal of the smear layer with an Er:YAG laser. Although they showed removal of the smear layer, photomicrographs showed destruction of peritubular dentine. The main difficulty with laser removal of the smear layer is access to the small canal spaces with the relatively large probes that are available.

Conclusion

Contemporary methods of root canal instrumentation produce a layer of organic and inorganic material called the smear layer that may also contain bacteria and their by-products. This layer covers the instrumented walls and may prevent the penetration of intracanal medications into the dentinal tubules and interfere with the close adaptation of root filling materials to canal walls. The data presented indicate removal of the smear layer for more thorough disinfection of the root canal system and better adaptation of materials to the canal walls. There are, however, no clinical trials to demonstrate this. Current methods of smear layer removal include

chemical, ultrasonic and laser techniques – none of which are totally effective throughout the length of all canals or are used universally. However, if the smear layer is to be removed the method of choice seems to be the alternate use of EDTA and sodium hypochlorite solutions. Whilst much is known about individual irrigants, their use in combination and their interactions (and in some cases precipitates) is less well understood. Conflicting reports exist regarding the removal of the smear layer before filling root canals. As several new sealer and core materials have recently been introduced, further investigations are required to determine the role of the smear layer in the outcome of treatment.

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