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Endodontics and the Smear Layer: History, Effects and Approaches for Removal

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The smear layer is the accumulation of mineralized and organic matter during endodontic therapy. The history of smear layer, its effect and approaches for removal are described in this review. The approaches for removal of smear layer include chemical removal, ultrasonic removal, laser removal and a combination of these approaches. In spite of diversity of opinions as to removal of the smear layer the general consensus stands in favor of removal of smear layer and the authors concur with the opinion that smear layer must be removed for better results in endodontic.

Keywords:Endodontic; smear layer; EDTA; NaOCl; ultrasonic; laser.

1. INTRODUCTION

The cutting of teeth using hand or rotatory instruments often results in accumulation of debris comprising of mineralized collagen matrix and organic matter often referred as smear layer [1]. During endodontic therapy such a smear layer is composed of dentin, pulp tissues, necrotic tissue and bacteria is always formed on the canal walls [2,3]. Although not visible with

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routine microscopy, such a layer has amorphous granular and irregular particles [4] as visualized with scanning electron microscopy. The presence of such a layer can act as a source for growth of microbes and minimize the ability of disinfecting agents to penetrate the dentinal tubules [2,5-7], and the smear layer, being a loosely adherent structure, should be completely removed from the surface of the root canal wall because it can harbor bacteria and provide an avenue for leakage [7-10]. Conversely other research groups are of the view that the smear layer may alter the dentinal permeability and block the dentinal tubules and limit bacterial or toxin penetration [1,3,11]. Clinicians often use irrigants to clear such debris during endodontic therapy. Approaches to remove the smear layer include the use of chemical irrigants [1,12,13], ultrasonic removal [14,15] and laser removal [16-18] with each of the methods having its own advantage. In the current review we describe the lesser known facts and the current concepts of smear layer during root canal therapy.

2. HISTORY AND SIGNIFICANCE OF SMEAR LAYER

McComb and Smith [19] were probably the first researchers to mention that the smear layer accumulates on the surface of root canals during instrumentation and these workers and Cotton [1] were of the view that the smear layer comprised of dentine pulp tissue and bacteria. Reports described that the debris of dentine and organic matter actually form the smear layer [1,20] Researchers found that the evaluation of such a layer requires scanning electron microscopy as the smear thickness is 1 μm [21] and was largely inorganic in composition. The presence of such a layer was noticed around instrumented canal surfaces. The thickness of 1–2 μm was observed in another study [7].

Root canal treatment usually involves the chemo mechanical removal of bacteria and infected dentine from within the root canals. The process is often followed by an intra-canal 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 [9,12,22-26]. The question of keeping or removing the smear continues to be debatable [27,28]. Some authors suggest that maintaining the smear layer may block the dentinal tubules and limit bacterial or toxin penetration by altering dentinal permeability [6,10,11]. Others however, 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 harbor bacteria and provide an avenue for leakage [7-9,24]. Based on investigations that smear layer could be a good source for bacterial growth its removal has been previously suggested [29,30], Removal of smear layer has also been suggested on account of the effect of smear layer on apical and coronal micro-leakage [21,31,32], bacterial penetration of the tubules [9,33] and the adaptation of root canal materials [34-36].

3. TYPES OF INSTRUMENTS AND THE AMOUNT OF SMEAR LAYER

Only few studies have addressed the effect of instrument type on the amount of smear layer generated. Mechanical preparation is considered to produce large amount of smear layer [3]. Few studies found that the rotatory instrument type had a significant effect on the amount of smear layer generated [28,37,38]. The number of cutting edges, their diameter and the rotatory files of the instruments affect the amount of smear generated [3]. However, one study noticed no difference in the amount of smear layer between canals with different tapers [2,39]. The use of coarse diamond burrs produce a thicker layer compared to carbide burrs [10,40]. Hand instruments are also considered to produce severe smearing of the dentin due to application of high forces [2].

4. THE EFFECTS OF SMEAR LAYER

The presence of smear layer is considered to prevent the dentinal fluid from flushing the dentin surface and retard the process of chemical adhesion [2,10]. The smear layer is also considered to lower dentin permeability and act as a barrier thus preventing fluid passage [41] and also delay the passage of endodontic sealers and root filling materials [34,42]. Considerable reduction in the tensile strength of cementing medium is known to occur in the presence of smear layer [2,16]. It is also known that the micro-leakage is increased in the presence of smear layer [16,43]. A few reports however, do not concur with the negative effects of the presence of smear layer [31,44]. Clinicians however often use various irrigants to remove the smear layer during endodontic.

5. APPROACHES FOR REMOVAL OF SMEAR LAYER

Three approaches have been mentioned for removal of the smear layer recently [3,6] and include the use of chemicals, ultrasonic, laser and their combinations.

5.1 Chemical Removal

Various chemicals used for smear layer removal include sodium hypochlorite, chelating agents such as EDTA, organic acids and their combinations [2,3,12].

5.1.1 Sodium hypochlorite (NaOCl)

NaOCl has the ability to kill microbes and dissolve organic tissues [5,7,45,46] and this increases with rising temperature [47]. However, its capacity to remove smear layer from the instrumented root canal walls has been considered to be low [48,49] as it only dissolves the organic material. The best results were obtained when 1% NaOCl was followed by 10% citric acid solution infusion. The acid solution allowed disorganization of the debris layer, while the hypochlorite finished the cleaning of dentinal walls [11,13].One percent sodium hypochlorite, 10% citric acid and 0.9% saline represented the best chemical treatment in smear layer removal consequently exposing the dentinal tubules, when compared to the use of 0.9% saline solution or combined with Carisolv ® or with 1% sodium hypochlorite solution [11,13].

It has been mentioned that sodium hypochlorite has three important properties; it is anti-microbial, dissolves pulpal remnants and debris and only slightly irritates the vital tissue [11,13,50]. The concentrations of NaOCl in endodontic therapy vary from 0.5% to 5.25% [51]. Clinicians must evaluate the contact time (10 to 40 min) and volume (10-20 mL) of NaOCl depending upon the rotatory canal preparation technique used and case to case [52,53]. Also NaOCl is caustic and accidental extrusion into apical tissue or maxillary sinus can lead to emphysema that must be viewed seriously and appropriate therapy should be instituted immediately [54].

5.1.2 Chlorhexidine (CHX)

CHX is considered a potent antiseptic used at concentrations of 2% for root canal irrigation [55], however, it did not show any dissolving capability towards organic material or removing effect on smear layer [2,56]. The concurrent use of NaOCl and CHX should be avoided as both are insoluble in each other and a brownish orange precipitate is formed with carcinogenic effects [8,51]. It has been suggested to wash the residual NaOCl with alcohol or EDTA before using CHX [8,15].

5.1.3 Chelating agents

Chelating agents interact with calcium ions present in the dentin wall and form soluble calcium chelates [2,3]. EDTA is considered one of the most common chelating irrigants in endodontics [2,3]. It has been reported that EDTA decalcified dentine to a depth of 20–30 µm in 5 min. [7,57]. However, Fraser [58] found that the chelating effect of EDTA was negligible in the apical parts of the root canal. A 3- minute application of EDTA in the root canal has been advised for the removal of smear layer and cleaning of the canal walls before the hermetic three dimensional obturation [15,59]. Crumpton et al. [60] showed that the smear layer was efficiently removed with the final rinse of 1mL of 17% EDTA for 1 minute followed by 3 mL of 5.25% NaOCl. Another study showed that this protocol was not efficient to completely remove the smear layer, especially in the apical third [14,61].

EDTA is commercially available in the form of liquid and paste type chelating agents [12] and usually contains 15-17% EDTA. One of the liquid preparations REDTA (Roth International, Chicago, USA) contains 17% EDTA with 0.84 g cetrimide, 9.25 mL (5M) sodium hydroxide and distilled water. McComb and Smith [19] 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 [62]. Another commercial preparation includes EDTAC with 15% EDTA and cetrimide. Goldberg and Abramovich [4] observed that the circum pulpal surface had a smooth structure and that the dentinal tubules had a regular circular appearance with the use of EDTAC. 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 [63]. This study also showed that REDTA was the most efficient irrigating solution for removing smear layer. Teixeira et al. [64] have however, shown that EDTA irrigation for 1, 3, and 5 minutes were equally effective. Studies using a combination of 0.2% EDTA and a surface-active antibacterial solution, [1,65] observed that this mixture removed most of the smear layer without opening many dentinal tubules or removing peri-tubular dentin.

The addition of other agents to EDTA has been experimented. The addition of surfactants to EDTA resulted in no extra benefit [66]. The addition of quarternary ammonium bromide to EDTA has also not shown any promising improvement [3]. A commercial product “Smear clear” (SymbronEdo, Orange, CA, USA) containing 17% EDTA, cetrimide, polyoxythylene and isooctyl-cyclohexyl showed good effectiveness in removing the smear layer in coronal and middle thirds [2,67].

Another chelating agent Bis-dequalinium-acetate (BDA), dequalinium compound and an oxine derivative has been shown to remove the smear layer throughout the canal, even in the apical third [1,68,69]. BDA has a low surface tension allowing good penetration and is considered to be well tolerated by periodontal tissues. Its toxicity is lower than NaOCl and thus can be used as a root canal dressing. Since 1980 BDA has been available commercially as Solvidont (De Trey, A.G., Zurich, Switzerland) and its use has been supported experimentally as an alternative to NaOCl [1,70-74]. Salvizol (Ravens Gmbh, Konstanz, Germany) contains 0.5% BDA and possesses the combined actions of chelation and organic debridement. Kaufman et al. [68] 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 [75]. However, Berg et al. [76] found that Salvizol was less effective at opening dentinal tubules than REDTA.

The effects of another combination ethylene glycol-bis (ß-aminoethyl ether)-N,N,N’, N’-tetra-acetic acid (EGTA) with EDTA were studied by Calt and Serper, [77]. Although EDTA removes the smear layer completely however, it causes erosion of the peritubular and intertubular dentine, whilst EGTA was not as effective in the apical third of root canals. Reports also mention that EGTA bind calcium more specifically [1,78].

Reports also mentioned that doxycycline hydrochloride (100 mg mL-1) was effective in removing the smear layer from the surface of instrumented canals and root-end cavity preparations [1,79]. Similarly, other reports showed that 1% tetracycline hydrochloride or 50% citric acid was effective in removing the smear layer from surfaces of root canals [1,80]. Based on these findings researchers developed a new irrigating solution containing a mixture of a tetracycline isomer, an acid, and a detergent (MTAD) [5,81]. 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 demineralize dentine faster than 17% EDTA [82] and bacterial penetration into filled canals is similar with both solutions [83].

The paste type chelators have been described previously with their effects on demineralization, dentine hardness and permeability [12] however their use for smear layer removal was negligible.

Prolonged exposure to EDTA and other chelating agents can weaken the root dentin [84] and increase the risk of perforation during mechanical root canal instrumentation [8,51]. Alternatively irrigation of root canal using solutions of sodium hypochlorite and EDTA has been suggested to be more promising [85].

5.1.4 Organic acids

The surface:mass ratio is large in the smear layer with very tiny particles, which makes them soluble in acids [86]. Weak acids such as maleic acid [87] and citric acid [88] have been used for removal of the smear layer [10]. The effectiveness of citric acid as a root canal irrigant has been demonstrated [88,89] and confirmed to be more effective than NaOCl alone in removing the smear layer [90].Citric acid removed smear layer better than poly acrylic acid, lactic acid and phosphoric acid but not EDTA [91].

Wayman et al. [5] showed that canal walls treated with 10%, 25% and 50% citric acid solution were generally free of the smear 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. [92] 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. Using 50% lactic acid, the canal walls were generally clean, but the openings of dentinal tubules did not appear to be completely patent [5].

Statistically significant difference between 5% and 50% citric acid solutions with a pH buffered to 6 were observed [4]. Paired analysis of groups having different pH values but the same concentration revealed that the lower concentrations (5% and 10%) with lower pH values removed smear layer more efficiently but no significant differences for higher concentrations (25% and 50%) were detected between low and high pH values [4,93].

Hennequin et al. [94] noted that although no conditioning effect is needed, irrigating with citric acid solution at a pH of 1.8 is sufficient to clean the walls of the canal. In accordance with the previous results of Haznedaroglu and Ersev[80], 50% citric acid with its original pH (1.1) not only removed the smear layer, but also caused extensive demineralization, widened the tubular apertures, and removed almost all peri-tubular dentin, which will probably lead to softening of the dentin [4,93].

Garberoglio and Brannstrom, [28] pointed out that a low pH (e.g., 1.5) for the irrigating solution could have adverse effects on the peri-apical tissues. Chemical agents with minimum destructive effect on dentin and without toxic side effects should be preferred. Citric acid was reported to be effective on anaerobic microorganisms and less cytotoxic than EDTA. In addition, citric acid is easily attainable and inexpensive [4,93].

A 25% solution of tannic acid has been used as a root canal irrigant and cleanser [1,95]. Compared to a combination of hydrogen peroxide and NaOCl, the smear layer removal was better and the canal walls were significantly cleaner and smoother. However other workers refuted these findings stating 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 [50,96].

The efficacy of 20% polyacrylic acid with REDTA was compared and found that it was no better than REDTA in removing or preventing the build-up of smear layer, on account of its higher viscosity [19]. Polyacrylic acid used at 5%and 10% as an irrigant was found to remove smear layer in accessible regions [62]. Commercial preparation containing 40% of polyacrylic acid (Durelon liquid and Fuji II liquid) has been observed to be efficient in smear layer removal by application for 30 seconds [50.97].

Maleic acid has been in use as acid conditioner in some of the adhesive systems. It has been reported to remove the smear layer present in cavities prepared for adhesive dentistry. Maleic acid is a mild organic acid used as an acid conditioner in adhesive dentistry [8,87]. Effective smear layer removal takes place at5% and 7% concentration, however at 10% or more it can result in demineralization and damage to the root canal wall [98]. At 7%, maleic acid has proved to be more efficient than 17% EDTA in removal of the smear layer from the apical third of the root canal system [87]. It also produces maximum surface roughness as compared to 17%EDTA, which plays an important role in micromechanical bonding of resin sealers. However, further evaluation is needed regarding the biological effects and technique of use of maleic acid on peri-apical tissues before routine clinical use can be employed.

5.2 Ultrasonic Removal

Following the introduction of dental ultrasonic devices in the 1950s, ultrasound was investigated in endodontics [1,99-101]. Irrigation of canals by continuous flow of NaOCl activated by an ultrasonic delivery has been observed to result in smear free surfaces during endodontic [8,14,15,102,103]. The concentrations of 2–4% sodium hypochlorite in combination with ultrasonic energy effectively removed the smear layer however; lower concentrations of the solutions resulted in suboptimal activity and were thus considered unsatisfactory [104].

Modified ultrasonic instrumentation using 1% NaOCl was found to remove the debris and smear layer more effectively [105] than the technique recommended previously [106]. 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. Studies comparing the effect of period of ultrasonic irrigation [13,102] noticed that a 3- and 5-minute irrigation resulted in smear-free canal walls, yet 1-minute irrigation was ineffective. However, other investigators noticed that ultrasonic preparation was unable to remove the smear layer [107-109]. Researchers also found that the cleaning effects of ultrasonic were beneficial only for the final irrigation of root canal after completion of hand instrumentation [7,15,104,105].

This is given the term passive ultrasonic irrigation [1] and has been the subject of a recent review [110]. Ahmad et al.[105,111] 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. Walker and Del Rio [112,113] observed that there was no difference between tap water and sodium hypochlorite when used with ultrasonic, and neither solution was effective at any level in the canal to remove the smear layer ultrasonically.

Lumley et al. [114] and other study [13] mentioned that only size 15 files be used to maximize micro-streaming for the removal of debris. Prati et al. [115] also achieved smear layer removal with ultrasonic. Baumgartner and Cuenin [116] also observed that ultrasonically energized NaOCl, even at full strength, did not remove the smear layer from root canal walls. Guerisoli et al. [117] evaluated the use of ultrasonic 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.

Yeung et al. [118] showed that a combination of 5 mL of 17% EDTA with the endo activator eliminated smear layer from a curved apical third of root canals more efficiently. A study by Kowsky and Naganath [119] concluded that the application of commercially available Endo Vac system enhanced the smear layer removal at the apical portion of curved canals. A recent meta-analysis recommended that ultrasonic irrigation improve intra canal cleanliness and smear layer removal compared to conventional needle irrigation and thus is recommended to be used throughout the root canal preparation [2,120].

5.3 Laser Removal

In endodontics lasers have been used to vaporize tissues in the main canal, remove the smear layer and eliminate residual tissue in the apical portion of root canals [7,121-123].

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 [16,17,124,125].

Dederich et al. [124] and other reports [6,16] used variants of the neodymium–yttrium-aluminium-garnet (Ne:YAG) laser and reported a range of findings from no change or disruption of the smear layer to actual melting and re-crystallization of the dentine. This pattern of dentine disruption was observed in other studies with various lasers, including the carbon dioxide laser [125], the argon fluoride excimer laser [126], and the argon laser [17,127].

Takeda et al. [121-123] using the erbiumyttrium-aluminium-garnet (Er:YAG) laser, demonstrated optimal removal of the smear layer without melting, charring or re-crystallization associated with other laser types. Kimura et al. [128] 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 peri-tubular 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. Al Zand et al. [129] mentioned that although the application of laser during endodontic therapy is safe yet it has some limitations [2] as it cannot access small curved canal spaces with the large probes.

The use of Er:YAG (erbium:yttrium-aluminum-garnet) laser (wavelength 2.94 μm) as a co adjuvant of conventional endodontic therapy lead to the removal of debris and smear layer from root canal walls by ablation [3], i.e. micro explosion of water molecules from dental tissues, breaking the hydroxyl group from hydroxyapatite [130]. The dental mineral has a strong absorption maximum near 2.8μm wavelength due to the hydroxyl ion symmetric stretch and a broad absorption band owing to interstitial water cantered at the 3μm wavelength. Owing to the similarities with the wavelength of the Er:YAG lasers, the interaction of irradiation lasers is effective on the root canal walls [130].

The teeth treated with a final 17% EDTA irrigation or Er:YAG laser application presented statically similar leakage value [3]. Tukey test also showed that the use of liquid adhesive significantly reduce coronal leakage when compared to the group in which it was not used

[3,130].17% EDTA or Er:YAG laser were used to remove smear layer formed after instrumentation to improve the contact of the dentine walls [130]. The Er:YAG laser wavelength (2.94 μm) has excellent interaction with water. This characteristic allows the laser to interact with the tooth hard tissue leading to thermo mechanical ablation of the mineralized tissue with no healing of the tooth that could cause pulp and peri-apical tissue damage. This laser also removes smear layer from the dentine walls, resulting in opening of the dentine tubules [130].

Saraswathi et al. [131] reported that 940 nm diode laser irradiation of root dentin along with NaOCl and EDTA irrigation resulted in better removal of smear layer without significant additional loss of mineral content. Yet, another study [132] aimed to demonstrate the effectiveness of different techniques and lasers on smear layer removal using NaOCl, 17% EDTA, MTAD, Nd:YAG, or Er:YAG. They reported that smear layer removal by EDTA solution demonstrated the best irrigation technique in all regions, and the effect of EDTA was statistically significant in the coronal and middle thirds only compared to MTAD. Thus, although alternative materials and techniques were used to improve smear layer debridement, still the combination of EDTA and NaOCl remains the best technique [2,3].

6. CONCLUSION

It was concluded that the smear layer is a microscopic layer comprising of organic and inorganic material formed during instrumentation in endodontics that often hinders treatment and the current consensus is in favor of removal of this layer by chemical irrigation, ultrasonic and laser or their combinations.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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