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THE SMEAR LAYER REVISITED

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Abstract

The smear layer is created on hard tissues of the teeth whenever they are cut with hand or rotary instruments. This thin (1-2 microns) layer of denatured cutting debris is very tenacious and is often the surface to which restorative materials are luted. The solubility characteristics, chemical reactivity and the structure-function relationships of this layer have not been well-defined. During creation of the smear layer, cutting debris is forced into variable distances into dentinal tubules. These so-called smear plugs, together with the smear layer decreases dentin permeability, dentin sensitivity and surface wetness. Bonding adhesive resins to smear layers appears to limit the theoretical bond strength unless the smear layers are loosened or partially removed. While confusion persists whether the smear layer should be kept or removed in restorative dentistry, removal of this layer is important for the success of endodontic treatment. Its removal is obtained using chemical solutions during root canal preparation such as Ethylene Diamine Tetra acetic acid (EDTA) preparations, combination of EDTA and sodium hypochlorite solutions, organic acids and lasers. The aim of this paper is to briefly review general concepts concerning the smear layer: its structure and composition, role of smear layer in restorative dentistry and endodontics.

Introduction

The smear layer is defined as an amorphous film or a deformed layer of organic and inorganic matter which is produced by reduction or instrumentation of dentin, enamel or cementum (1). When tooth structure is cut using hand or rotary instruments, the mineralized matrix does not shred. Instead, it shatters and considerable amount of debris made up of mineralized collagen matrix is produced. This exists at the junction of the restorative material and the dentin matrix to form the smear layer (1,3).

When the root canal is instrumented during endodontic therapy, a smear layer consisting of dentin, pulp tissues, odontoblastic processes, necrotic tissue and bacteria is always formed on the canal walls. Under low magnification, it appears amorphous, irregular and granular. At higher magnification it shows a granular substructure composed of particles with an approximate diameter of 0.05-0.1 micrometer. These particles represent an enormous surface area to mass ratio rendering the smear layer prone to dissolution by acids and chelating agents (4).

The smear layer was an unknown and unrecognized entity for years (2). Being a mineralized structure, it used to get completely demineralized and could not be seen under the light microscope (5). In 1963, Boyde and Steward used a scanning electron microscope and referred to the grinding debris as 'smear layer' (5). In 1975 it was first described by McComb and Smith (2).

Despite the continuous studies and research undertaken, the question still remains if the smear layer should be present or absent under restorations (2). It acts as a natural bandage over the cut dentinal surfaces and reduces dentin permeability by 86% by blocking the tubules and limiting bacterial toxin penetration. But it is still a porous layer and it forms only a weak attachment to the underlying dentin which disintegrates over time leading to micro leakage (6). Moreover the smear layer may be infected and acts as a reservoir of microorganisms and their byproducts which survive, multiply and grow deeper into the dentinal tubules (7). In endodontics, the removal of the smear layer and the smear plug has been practiced to allow for better adaptation of sealers and gutta percha with the root canal walls; for better diffusion of intracanal medicaments and for preventing micro leakage (2).

Composition

In restorative dentistry, the smear layer is composed of denatured collagen, hydroxyapatite and other cutting debris (2). It is seen that the superficial layer of dentin is more important because the bond strength of all adhesive systems is always 50% more in this layer. This can be attributed to the fact that the smear layer found in deep dentin contains more organic material than those found on the superficial dentin (4).

The composition of the smear layer in endodontic is composed of an organic and an inorganic portion. The inorganic content of the layer is higher.

Organic portion: (1) Heated coagulated proteins

(2) Necrotic and non-necrotic pulp tissues

(3) Odontoblastic process

(4) Saliva

(5) Blood cells

(6) Micro organisms (2)

Inorganic portion: (1) Hydroxyapatite crystals

(2) Minerals from dentinal tubules (2)

However, in the early stages of instrumentation, it may be mostly organic due to the presence of necrotic or viable pulpal tissue (8).

PARTS

The smear layer is a bilaminar structure present on all restoratively or endodontically treated dentinal surfaces unless it has been treated with acid or chelating agent. It has an average depth of 1-5µm. The depth entering the dentinal tubules may vary from a few microns upto 40µm (2,9).

The two parts of the smear layer are: 1) The superficial layer

2) The deep layer (2, 4)

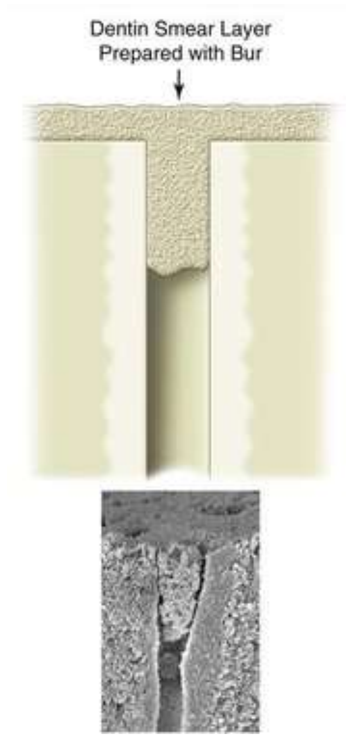

fig 1

Fig 1 shows the different parts of the smear layer(10)

<u>The outer layer (superficial layer)</u> is thin, amorphous, easy to remove and about 1-5 µm thin (2). It lies on the actual tooth surface, covering or overlying the tubules and intertubular dentin. Various factors will determine the depth of this layer (3).

In restorative dentistry, dry cutting of dentin produces a thicker layer as compared to when dentin was cut with a water coolant(5). Use of coarse diamond burs produces a thicker layer than carbide burs, which produces a thicker smear layer than finishing burs (11). Hand instruments also produce severe smearing of the dentin due to application of high forces during mechanical excavation. The smear layer produced with high speed is more difficult to remove than that produced with low speed (12).

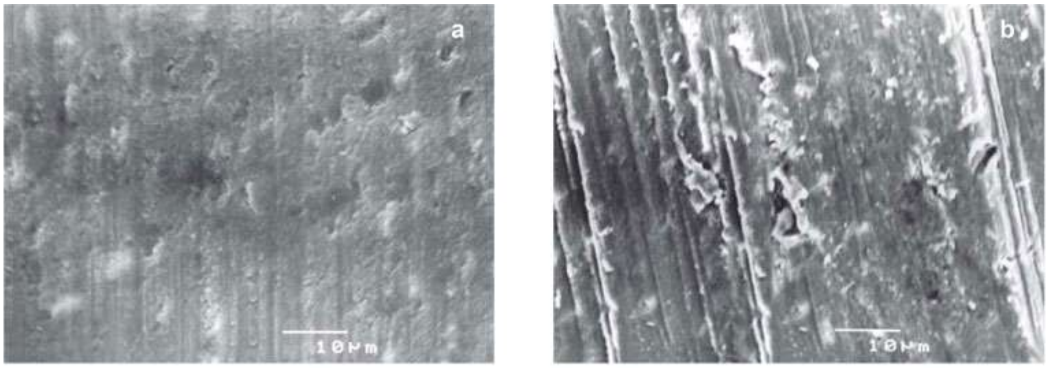

FIGURE 3- Dentin surface cut by: a) carbide bur; b) diamond bur. (Original magnification 1500X, bar=10 µm)

fig 2

Fig 2 shows the morphology of smear layer produced by a carbide and diamond bur.(13)

In endodontics, filing a canal without irrigating it regularly will produce a thicker smear layer than those in which constant canal irrigation is done (2). The closer the instrument to the dentinal walls (narrow canals) the more is the centrifugal force and the smear layer will be thicker and more resistant . The thickness of smear layer found with the use of different endodontic instrument in increasing order was found to be as hand files, profiles and protapers (4). Use of sodium hypochlorite with EDTA was found to be more effective in reducing or removing the smear layer because of the synergistic action of the two

The deep layer (inner layer/ smear plugs/loosely attached layer): This layer consists of materials which have been forced into the dentinal tubules, forming a smear plug which occludes the tubules and strongly adheres to the canal walls (2). These can extend upto 40µm into the tubules.

Many theories have been proposed to describe the formation of the smear layer. Brannstrom and Johnson concluded that this packing of the smear plugs was due to the rotatory action of burs and endodontic instruments. This rotation causes the centrifugal scattering of the smear material which enters the tubules if they are oriented properly. Cengiz proposed that the adhesive forces between the dentinal tubules and the smear material formed smear plugs by capillary action (4, 14).

Morphology

When a tooth is cut or abraded with an instrument, a large amount of energy is generated. This frictional heat causes plastic and elastic deformation which can alter and deteriorate the surface of the tooth structure. Eirich (1976) stated that smearing occurs when hydroxyapatite crystals within the tissue are plucked out or broken or swept along. This hydroxyapatite will rest within the smeared matrix and lower the surface energy (5).

In restorative dentistry, when tooth structure is cut, the matrix shatters and produces considerable amount of debris (2, 3). When this is viewed under low magnification, steel and tungsten carbide burs produce troughs which run perpendicular to the direction of the handpiece. Fine grooves are seen which run parallel to the rotating bur. This phenomenon is called as galling and the frictional humps represent a rebound effect of the bur against the tissue (5).

fig 3

Fig 3 showing an SEM picture of the galling pattern on a dentin surface(15)

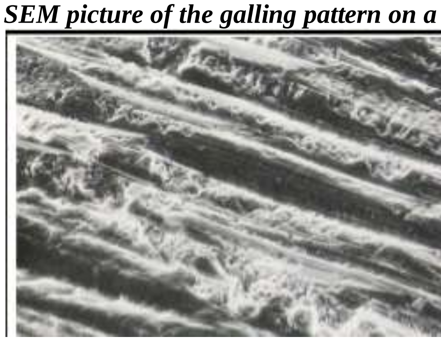

fig 4

Fig 4 showing grooves traversing the dentin surface abraded with diamond(15)

The galling phenomenon is more marked with tungsten carbide burs running at high speeds. This arises when the flutes of the bur wear away to produce abrading points and scratch the dentin surface. As the cutting edges wear away, the cutting efficiency of the bur is reduced. This will increase the frictional heat and cause smearing (5).

While some portions of the smear layer are firmly attached to the tissue surface, it may be lifted free by delamination in other layers. This may be due to severe dessication of the tissues during preparation for scanning electron microscopy (5).

During cavity preparation with laser, the ablation of sound enamel and dentin by Er:YAG laser promotes cavities with rough enamel margins and dentin surface, with irregular and rugged walls, which are free of smear layer (16).

IN ENDODONTICS

Once the root canal has been instrumented, the high magnification of electron microscope discloses the normal canal anatomy that has been lost and that a thick smear layer has been formed. The dentin surface of the canal appears granular, amorphous and irregular. The packing material shows a segmented appearance as if it had been packed in increments. Tubule packing is seen when less than half the circumference of the tubule has been fractured away. This packing phenomenon is not seen if more than half the circumference of the tubule has been fractured (2).

EFFECT OF THE SMEAR LAYER

Dental materials: The presence of smear layer in vital teeth will restrict the dentinal fluid from flushing the dentin surface. It also hinders the process of chemical adhesion that produces the marginal seal. The attachment of the smear layer to the underlying dentin is about 5 µm. The initial sealing process under amalgam restorations maybe compromised because of instability of the smear layer and its penchant for leaching under amalgam. This will produce a widening of the amalgam tooth micro-crevice and ultimately weaken the sealing mechanism. Therefore it does not allow for bonding of material to the dentin. In order to reduce the microleakage, a layer of liner should be applied before condensing amalgam. Glass ionomer cements, polycarboxylate cements and composite resins bond to

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the tooth structure by chemical means. However this chemical bonding may be affected in the presence of the smear layer (2).

Endodontics: When a canal is instrumented, the smear layer produced will remain within the canal and pulp chamber. The bacteria and its products in the smear layer can provide a reservoir of potential irritants. The long term durability of the smear layer is another factor to be considered while retaining it. It may crack open and pull away from the underlying dentinal tubules. This can hamper the gutta percha obturated over the smear layer. Therefore removing it will aid in better adaptation of sealers and obturating materials in the dentin by increasing the permeability of dentin (2).

Dentin permeability: Dentinal tubules act as a pathway for irritants towards the pulp. The diameter of the tubules at the pulpal end is greater than that at the dentinoenamel junction. This factor combined with the convergence of tubules towards the pulp increases the dentin permeability in the deeper layers. The smear plugs lower dentin permeability by forming a physiologic barrier to hydrodynamic fluid shifts and to bacterial toxins (17). The fluid flow is directly proportional to the tubule radius. Thus, removal of smear layer will increase the surface area available and increase permeation diffusion by 5-6 times and by convection by 25-36 times(3). These problems must be considered whenever dentin is etched to facilitate retention of a restorative material. If such restorations undergo microleakage or fracture, the etched dentin will be more permeable than the dentin with an intact smear layer (17).

Dentin sensitivity: Rapid movement of the dentinal fluid within the tubules will stimulate the A delta nerve fibers to produce a brief, sharp, well localized pain called dentinal hypersensitivity. Smear layer offers a major resistance to fluid movement across dentin which is an important mechanism of dentin sensitivity. It has been seen that 15 seconds of acid etching will increase the fluid movement by 20 times. This will result in an increased dentinal sensitivity if the dentin is not sealed with a restorative material (17).

Restorative materials or techniques which do not require the removal of smear layer tend to create less post-operative sensitivity. This is because the smear layer and plug complex account for 86% of the resistance to fluid movement across dentin (17).

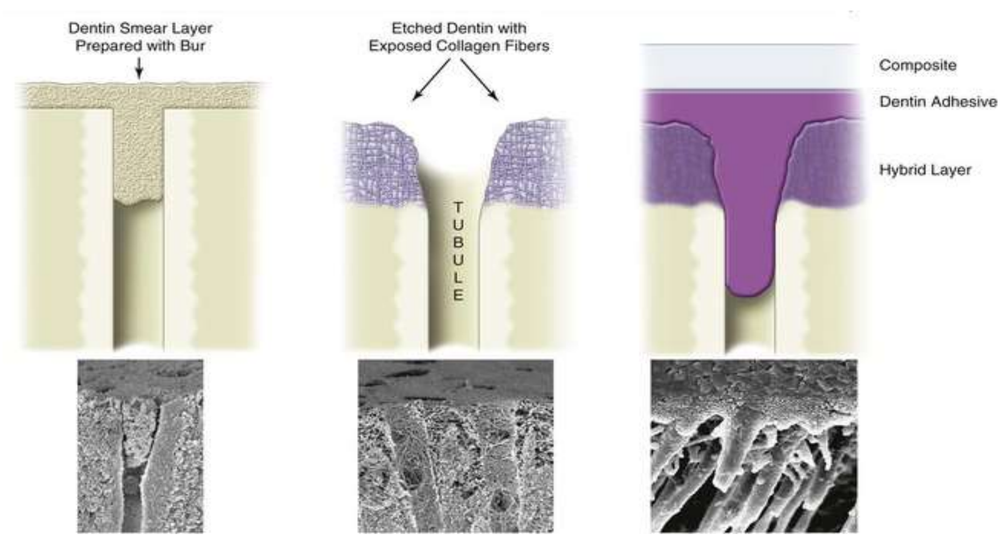

fig 5 ***Fig 5 showing removal of smear layer after acid etching and formation of resin tags(10)***

Role played in microleakage : Microleakage is defined as the movement or flow of oral fluids and bacteria into the microscopic gap between a prepared tooth surface and a restorative material. This can cause recurrent caries and sensitivity (18). Unfortunately, most restorative materials cause some amount of leakage due to solubility of cements, differences in coefficient of thermal expansion and inability of materials to adapt 100% to the walls of the tooth (4).

There are 3 possible routes for micro leakage:

1) Within or via the smear layer
2) Between the smear layer and cavity varnish/ cement
3) Between the cavity varnish/cement and the restorative material (3).

Williams and Goldman showed that the smear layer delayed the penetration of Proteus and Vulgaris. A. Viscosus and Cornybacterium are capable of digesting the smear layer however, they cannot remove the smear plugs. If the smear layer is removed by acid etching, then bacterial invasion into the dentinal tubules will take place a lot more easily.

Removal of smear layer decreases micro leakage but increases permeability.

Smear layer on root canal walls acts as a physical barrier and may reduce adhesion and penetration of the sealer into the tubules. If the smear layer is not removed, the durability of the apical seal should be evaluated over a long period. Since this layer is non-homogenous and weakly adherent it may get dislodged from the underlying tubules, slowly disintegrate, dissolve around a leaking filling material and create a void between the canal and the sealer. Penetration of the sealer in the smear free groups ranged from 4-60 micro meters as shown by Oksan et al in 1993 (4).

Post cementation: Removal of the smear layer increases the bond and tensile strength of the cementing medium. Glass ionomer cements are effective in post cementations after smear layer removal because, of better chemical union with the tooth structure.

When an unfilled BISGMA resin was used after sodium hypochlorite rinse, the strength of the resin bond was better than that of the polycarboxylate cement. When the smear layer was removed by flushing with EDTA and sodium hypochlorite , the BISGMA resin flowed into the exposed dentinal tubules and into the serrations on the post thereby improving the retention.

The use of a dentin bonding agent prior to cementing a post with a composite cement or a glass ionomer cement may or may not dictate removal of the smear layer depending upon which bonding agent is used or whether a glass ionomer cement is used (2).

REMOVAL OF SMEAR LAYER

Chemical removal: The quantity of smear layer removed by a material is related to its pH and the time of exposure . A number of chemicals have been investigated as irrigants to remove the smear layer. 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.

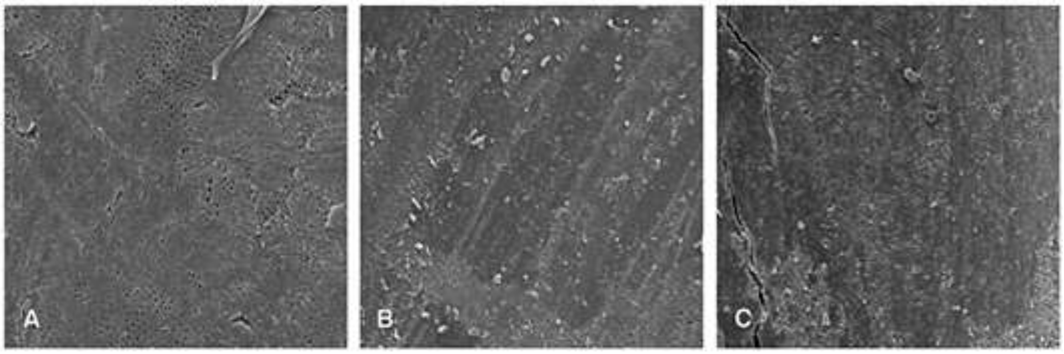

fig 6

Fig 6 showing the cervical, middle and apical third of dentin in which 2% chlorhexidine was used without EDTA(19)

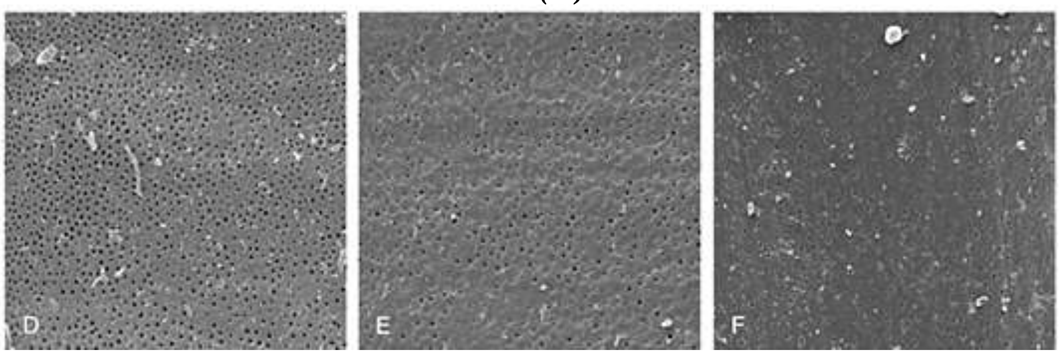

fig 7

Fig7 showing the cervical, middle and apical third of dentin in which 2% chlorhexidine was used with EDTA(19)

Chelating agents: Smear layer components include very small particles with a large surface : mass ratio, which makes them soluble in acids. The most common chelating solutions are based on EDTA which reacts with the calcium ions in dentin and forms soluble calcium chelates (Fig. 4). However, Fraser (1974) stated that the chelating effect was almost negligible in the apical third of root canals. 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. Cetrimide has been added to EDTA solutions to reduce surface tension and increase penetrability of the solution. However, there was still smear layer remaining in the apical part of the canal. A combination of 0.2% EDTA and a surface-active antibacterial solution, removed most of the smear layer without opening many dentinal tubules. 1% tetracycline hydrochloride or 50% citric acid can be used to remove the smear layer from surfaces of root canals. 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 MTAD which demineralized dentin faster than 17% EDTA.

Organic acids: The effectiveness of citric acid as a root canal irrigant has been confirmed to be more effective than NaOCl alone in removing the smear layer. Citric acid removed smear layer better than polyacrylic acid, lactic acid and phosphoric acid but not EDTA. 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 precipitates within the root canal.

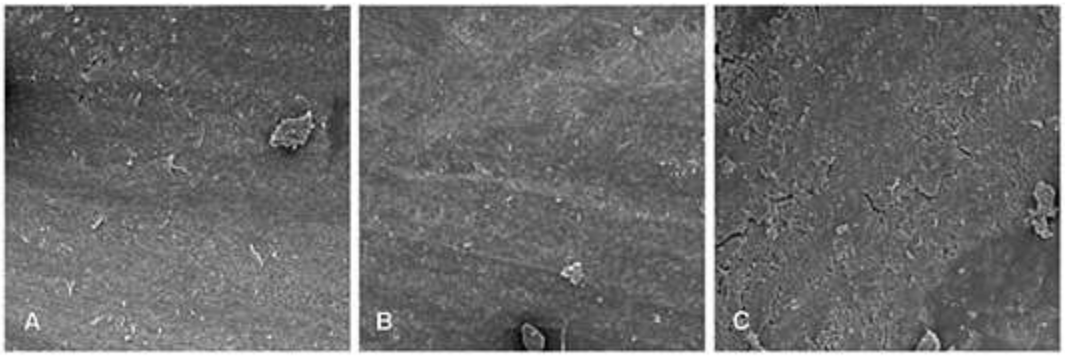

fig 8

Fig 8 showing the cervical, middle and apical third of the canal where 2.5% sodium hypochlorite was used without the use of EDTA.(19)

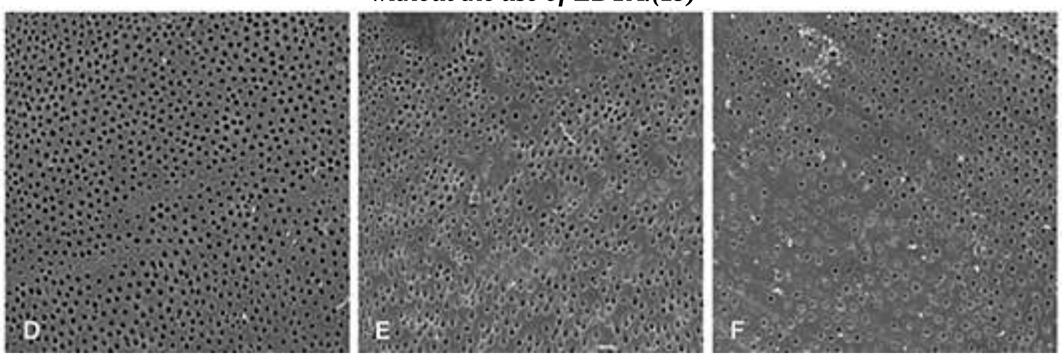

fig 9

Fig 9 showing the cervical, middle and apical third of the canal where 2.5% sodium hypochlorite was used with EDTA.(19)

<u>Sodium hypochlorite and EDTA</u>: When irrigating a root canal, the purpose is twofold: to remove the organic and the inorganic component of 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 used for the removal of smear layer as well as soft tissue and debris by the alternate use of EDTA and NaOCl.

<u>Ultrasonics</u>: When a concentration of 2% to 4% NaOCl activated by an ultrasonic delivery system was used for the preparation and irrigation of canals for 3 to 5 minutes, smear-free canal surfaces were observed. The apical region of the canals showed less debris and smear layer than the coronal aspects, as acoustic streaming is more intense in magnitude and velocity at the apical regions of the file. The files used for this purpose must be loose in the canal eg. size 15 files should be used to maximize microstreaming.

Lasers: 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. 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. Neodymium–Yttrium-Aluminium-Garnet (Nd:YAG), the carbon dioxide laser, the Argon FLuoride Excimer laser and the Argon Erbium- Yttrium-Aluminium-Garnet (Er:YAG) laser, can be used for removal of the smear layer. 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 (16).

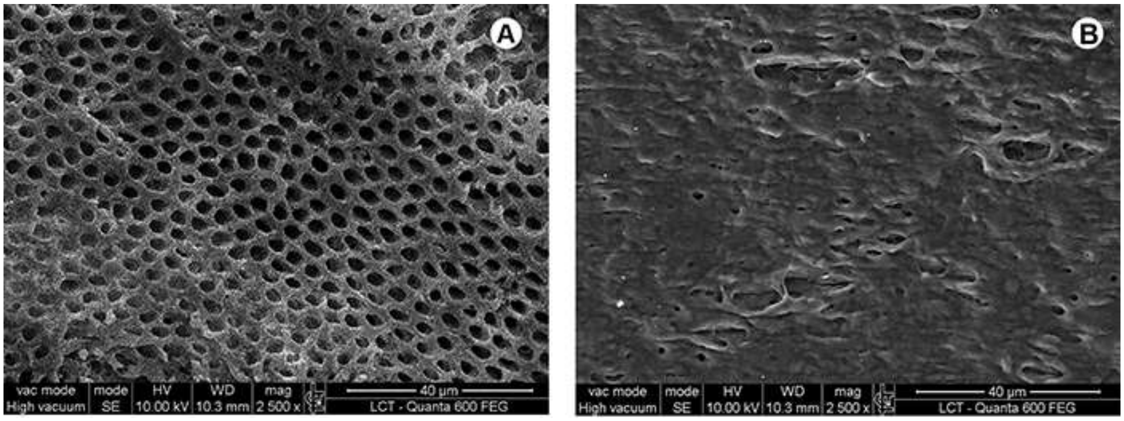

fig 10

Fig 10 A shows dentin free of smear layer with open tubules; B) shows dentin fusion and solidification after laser irradiation with no smear layer or debris(20)

Recent researches in smear layer

Various chemicals are used during endodontic treatment to remove the smear layer which may lead to alterations in root dentin and change its chemical and physical properties (21). Studies have shown that maleic acid was the best agent which removed smear layer from all thirds of the root canal. However it has shown to reduce the microhardness of dentin(22).

Another study has shown that smear layer removal in all thirds of the root canal could be achieved by activating 17% EDTA with ultrasonics(23).

When it comes to irrigation techniques EndoActivator performed the best cleansing for both smear layer and organic debris in all thirds of the root canal, followed by EndoVac and conventional irrigation(24).

Conclusion

There are two schools of thought regarding the smear layer. One is that it is protective in nature and so should be retained. The other is that it is contaminated and could be harmful in the long run. After weighing the pros and cons of this entity, the presently accepted concept is to remove the superficial smear layer while retaining or modifying the smear plugs.

In endodontics, the accepted concept is that the smear layer should be removed so that there is a fluid tight seal between the canal walls and the obturating material.

Despite the great number of commercially available smear layer removing agents and the several methods to use them, clinicians seem confused. More studies are required in order to clarify the role of the smear layer, the need to remove it and the best method to remove it in order to reduce microleakage and ensure successful outcomes of dental treatment.

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