SMEAR LAYER

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Introduction

Unknown and unrecognized for years, the smear layer has become a force to be reckoned with during the last decade. The full significance of the smear layer has been slow to be perceived. Its increasing importance has paralleled the interest in adhesive bonding to tooth structure. Its effect as a so-called "Cavity linear" is just beginning to be appreciated. As suggested by David Pashley, the smear layer as a cavity linear may unquestionably have both beneficial and detrimental effect. Thus, there is a need to alter the traditional procedures of restorative treatment to take advantage of the beneficial effects and to avoid the detrimental effects.

Definition

I] According to Operative Dentistry Journal (1984), the term smear layer applies to "any debris produced iatrogenically by the cutting, not only of dentin, but also of enamel, cementum and even the dentin of the root canal".

II] Cohen defined smear layer as "an amorphous, relatively smooth layer of microcrystalline debris whose featureless surface cannot be seen with the naked eye".

III] The American Association of Endodontics defined smear layer as "a surface film of debris retained on dentin or other tooth surfaces like enamel, cementum after instrumentation with either rotary instruments or endodontic files.

IV] According to DCNA (1990) when tooth structure is cut, instead of being uniformly sheared, the mineralized matrix shatter. Existing of the strategic interface of restorative materials and the dentin matrix most of the debris is scattered over the enamel and dentin surfaces to form what is known as smear layer.

History

→ It is difficult to say or by whom, the concept of the smear layer was first introduced.

→ The earliest studies on the effects of various instruments on dental tissues were those reported by Lammie and Draycott in 1952 and Street in 1952. These attempts were limited principally to light microscope.

→ Charbeneau, Peyton and Anthony were among the first to quantify and rank the difference between burs and abrasives by using a prolifometer to record the surface topography of cut and abraded dental tissues.

→ In 1961, Scott and O'Neel used transmission electron microscopy to study the nature of the cut tooth surface.

→ It was not until the advent of SEM that the grinding debris was first referred to as the smear layer by Boyde, Switzer and Stewart in 1963 and further defined by Eick and others in 1970, who referred to it as the smeared layer.

→ In 1972, Jones, Lozdan and Boyde showed that smear layers were common on enamel and dentin following the use of periodontal instruments.

→ Erich and others in 1970 attempted to quantify and identify cutting debris on tooth surfaces. They confirmed that:

- Surfaces abraded with diamonds were rougher than those cut with tungsten carbide burs.
- Surfaces cut dry were rougher and more smeared than those in which water was used as coolant.
- The smear layer is composed of an organic film less than 0.5µm thick. Included within it were particles of opacity ranging from 0.5-15µm. Such layers were present on all surfaces though they were not necessarily continuous.

→ In 1982, Goldman and others smear layers after the use of endodontic instrumentation.

→ Erich and co-workers in 1976 discussed the role of friction and abrasion in the drilling of teeth. They accounted for the formation of smear layers, especially in dentin, by a brittle and ductile transition and alternating rupture and transfer of apatite and collagen matrix onto the surface.

Components of the Smear Layer

→ The exact proportionate composition of the smear layer has not been determined, but SEM examinations have disclosed that its composition is both organic and inorganic.

→ The inorganic material in the smear layer is made up of tooth structures and some non-specific inorganic contaminants.

→ The organic components may consists of heated coagulated proteins, necrotic or viable pulp tissues and odontoblasts processes plus saliva, blood cells and microorganisms.

The Smear Phenomenon

→ In a dental context Eirich in 1976 stated that smearing occurs when "hydroxyl apatite within the tissue is either plucked out or broken, or swept along and resets in the smeared out matrix".

→ Studies have shown that temperature will rise up to 600° in dentin when it is cut without a coolant. This value is significantly lower than the melting point of apatite (1500-1800°C) and has led most to conclude that smearing is a physico chemical phenomenon rather than a thermal transformation of apatite involving mechanical shearing and thermal dehydration of the protein. Plastic flow of hydroxyl apatite is believed to occur at lower temperature than its melting point and may also be a contributing factor to smearing.

Morphology of the Smear Layer

→ The smear layer consists of two separate layers, a superficial layer, and a layer loosely attached to the underlying dentin. Dentin debris enters the orifices of the dentinal tubules and acts as plugs to occlude the ends of the tubules. The smear layer is not always firmly attached and neither is it continuous over the substrate. Smear layers found on deep dentin contain more organic material than those found on the superficial dentin.

→ Clinically, produced smear layers have an average depth of from 1-5µm (Goldman et al 1981, Mader et al 1984). The depth entering the dentinal tubule may vary from a very few µm to 40µm.

→ Cengiz et al (1990) proposed that the penetration of smear layer into dentinal tubules could be caused by capillary action as a result of adhesive forces between the dentinal tubules and the smear material. One can conclude that a smear layer is present on all restoratively or endodontically prepared teeth unless the dentin surfaces was treated with an acid or a chelating agent.

→ Several factors may cause the depth of the smear layer to vary from tooth to tooth; a) dry or wet cutting of the dentin, b) the type of instruments used and (C) the amount and chemical make-up of the irrigation solution.

→ Filing a canal without irrigation or cutting without a water spray will produce a thicker layer of dentin debris and the use of coarse diamond burs produces a smear layer than the use of carbide burs.

→ The differences in topographical detail after cutting dentin and enamel with steel and tungsten burs and abrading it with the diamond stones are clearly evident.

→ Steel and tungsten carbide burs produce an undulating pattern, the through of which run perpendicular with the direction of movement of the handpiece. Fine grooves can be seen running perpendicular to the undulations and parallel with the direction of rotation of the bur such a phenomenon is referred to as "galling" and the frictional humps represents a "rebound effect" of the burs against the tissue. The galling phenomenon appears more musked with tungsten carbide burs run at high speed. An examination of both steel and tungsten carbide burs shows a rapid deterioration of the cutting edges through what appeared to be a brittle #. Brittle # significantly diminishes the cutting efficiency of the bur, probably increases frictional heat and causes smearing.

Steel and Tungsten Carbide burs:

→ At higher magnification, these burs can be seen to have obliterated the normal structural detail of the tissue. Debris, irregular in shape and non-uniform in size and distribution remains on the surfaces even after thorough lavage with H_2O.

→ The mechanism by which burs remove dental tissue is significantly different from the abrading action of diamond. As burs rotate, the flute undermines the tissue, the amount being determined by such factors as the angle of attack of the flute. On the other hand, abrasive particles, passing across the tissue, plough troughs in which substrate is ejected ahead of the abrading particle and elevated into ridges parallel with the direction of travel of particle. Several factors govern the size of grooves, including particle size, pressure and hardness of the abrasive related to the substrate.

Diamonds	Steel and Tungsten Carbide Burs (Eames and Neile in 1973)
• Diamonds produce relative deep and uniform grooves. • Produce more rougher surface. • The grooves run parallel with the direction of motion of handpiece. • Coarse diamond abrasives used dry, produce the thickest deposits.	• Show less evidence of grooves. • Produce less rougher surface compared to diamond. • Grooves run perpendicular with the direction of motion of handpiece.

Bonding of the Smear Layer

A significant difference exists between diamond burs used with and without a coolant of water spray. In the absence of coolant smeared debris can be found commonly on the surface. The smeared debris does not form a continuous layer but exists rather as localized islands with discontinuities exposing the underlying dentin. Coolant of the water spray does not prevent smearing but appears to significantly reduce the amount and distribution of it.

<u>Functional Implications</u>

Dental Materials

→ DM scientists have been concerned about the smear layer in so far as it masks the underlying dentin matrix and may interfere with the bonding of adhesive dental cements such as polycarboxylates and GIC, which may react chemically with the dentin matrix.

Presumably, allowing cements to react chemically with the smear layer rather than with the matrix of sound tubular dentin, produces a weaker bond due to the fact that the smear layer can be torn away from the underlying matrix. When cements are applied to dentin covered with a smear layer and then tested for tensile structure, the failure can be adhesive (between cement and smear layer) or cohesive (between constituents of smear layer).

Restorative Dentistry

The question of microleakage of restorative materials is beyond the scope. It is worth mentioning however, that there are at least 2 or 3 routes by which subs can leak into the pulp. First, even if there were no gap between dentin and restorative material, bacterial products could theoretically diffuse around the material via small channels and interstices within the smear layer. Unfortunately, one cannot perfectly adapt amalgam or any other restorative material to the walls of a prepared cavity. Thus, there are voids and space between amalgam, and dentin that allow considerable microleakage. Most clinicians use a cavity varnish or liner to seal dentin.

I] Restorative Dentistry

→ Viewed in this theoretical prospectives, if one could produce a truly adhesive filling material that had no shrinkage upon polymerization and a co-efficient of thermal expansion close to that of tooth structure, then one would want to remove the smear layer and omit the use of any cavity liner or varnish that did not react clinically with both dentin and the resin.

There are 3 possible routes for micro-leakage:

- Within or via the smear layer.
- Between the smear layer and the cavity varnish or cement.
- Between the cavity varnish / cement and the restorative material.

→ At numerous points within such a complex 3-D structure, the routes interest permitting microbial products access to dentinal tubules and underlying pulp.

Bonding and Smear Layer

→ In general, diamonds, thru the introduction of grooved anomalies, produce a greater surface area than burs. The increased surface area probably offers a large number of retentive sites. These sites in enamel are primarily micromechanical and the retention mechanism for the tissue lies in the multitude of superficial micropores enhanced following acid conditioning of the tissue.

→ Acids are among several agents that can remove the smear layer. For enamel, $H3PO_4$ acid in gel / solution → ranging from 30-50% is most popular. Branstrom, Nordel Wall and Gwinnett demonstrated that conditioning facilitates the penetration of resin into the dentinal tubules.

This increases bond strength.

Influence of conditioning of S-L on sensitivity of dentin:

→ Etching the dentin of roots, whether done therapeutically or by the action of microorganisms of plaque, can remove the thin layer of covering cementum or smear layer or both, thereby conditioning with acids will remove the smear layer plugs (exposing patent dentinal tubules to the oral cavity). This can lead to sensitivity of the dentin to the point where it interferes with the patients oral hygiene.

→ Several studies indicate that most of the resistance to the flow of fluid across dentin is due to the presence of smear layer. Etching dentin greatly increases the ease with which fluid can move across dentin.

This is accompanied clinically by increased sensitivity of dentin to osmotic, thermal and tactile stimuli.

Influence on the permeability of dentin

→ Substances diffuse across dentin at a rate that is proportional to their concentration gradient and the surface available for diffusion.

→ The removal of smear layer increases the dentin permeability by 5-6 times in vitro by diffusion but increases it by 25-36 times by filtration.

Diffusion	Filtration / convection
- Occurs from area of higher concentration to lower. - The concentration of substance is dissipated over a distance. - πr^2	- Transport of materials thru dentin is due to the presence of a pressure gradient. - There is no change in the concentration of substance dissolved in the fluid as the fluid and all that is dissolved in it is made to flow from one patient to another. The driving force is pressure. - πr^4

Thus, movement of fluid across dentin by convection is much more sensitive to the degree of occlusion of tubules, i.e., the presence / absence of a smear layer, than is movement of substance by diffusion.

Bacteria in the smear layer under restorations:

→ The physiological consequences of the smear layer and whether it should be present or absent under restorations are rather complicated questions. To a great extent, they seem to be related to the presence of bacteria under restorations.

→ An in vitro study showed that water cleaned cavities with the smear layer remaining underneath the composite restorations showed the presence of numerous bacteria, whereas in the antiseptically cleaned cavities, bacteria were absent.

→ The fact that bacteria multiply on cavity walls even if there is no appreciable communications to the oral cavity seems to indicate that certain microorganism get sufficient nourishment from the smear layer and dentinal fluid.

→ These considerations favour the opinion that most of the smear layer should be removed and any smear layer remaining for instance at the tubule aperture should be antiseptically treated before the application of lining or a luting cement. It has also been suggested that bacteria are not present in freshly prepared smear layers.

→ There is no evidence that common permanent restorative materials are sufficiently antibacterial to kill bacteria entrapped within the smear layer, especially when a fluid filled contraction gap, 5-20μm wide, separates the restoration from the smear layer.

→ Bases of ZnOE and $Ca(OH)_2$ may have good antiseptic effects but, unfortunately under permanent restorations, these bases cannot be placed on all cavity walls.

→ Pure $Ca(OH)_2$ in an excellent antibacterial temporary dressing and should be applied under temporary fillings.

→ It is also possible but not proved that $Ca(OH)_2$ may reinforce the remaining smear plugs in the outer apertures of dentinal tubules.

→ The protective effects of smear plugs in tubule apertures and the consequence of removing the plugs:

→ In a study 11 years ago they found that etching the cavity prior to the placement of composite resin resulted in a massive invasion of bacteria in dentinal tubules. This was seen in all teeth after 2-4weeks. The corresponding cavities, cleaned by water and with smear layer, had a bacterial layer on the cavity walls but practically no invasion into the dentinal tubules. Obviously smear plugs in the apertures of the tubules had prevented bacterial invasion. Inflammation was present under all infected cavities, being somewhat more pronounced on the etched cavities, but the difference was not great. This another conclusion, from this study was that smear plugs did not prevent bacterial toxins, from diffusing into the pulp.

→ From opened tubules bacteria may easily reach the pulp and multiply because removal of smear plugs should be avoided.

→ Another important consequences of etching and removal of smear plugs and peritubular dentin at the surface is that the area of wet tubules may increase from about 10-25% of the total. Subsequently, it is difficult to get the dentin dry because fluid continues to be supplied from below through the tubules. This moisture would not seem to favour adhesive or mechanical bonding to dentin.

Pulpal Irritation due to removal of the smear layer

→ In several experiments, we found that 37% phosphoric acid or 50% citric acid applied for 15 seconds or 1 minute does not result in any appreciable pulpal reaction, inflammation or necrosis.

→ Acid etchants, detergents, a thin mix of phosphate cements, GIC, and resins do not produce any appreciable damage and inflammation to the pulp, not even when applied to exposed pulp.

→ However, for reasons already mentioned the cut dentin should not be treated with acid or EDTA in such a way that the tubules become open and widened

Endodontics

Role of smear layer in Apical Leakage

→ The smear layers presence plays a significant part in an increase or decrease in apical leakage. Its absence makes the dentin more conducive to a better and closer adaptation of the gutta-percha to the canal wall. With the smear layer intact, apical leakage will be significantly increased. Without the smear layer, the leakage will still occur but at a decreased rate.

→ Plasticized gutta-percha can enter the dentinal tubules when the smear layer is absent. This can establish a mechanical lock between the gutta percha and the canal wall.

Effect of Smear layer on Sealers

→ The type of sealer used has different implications once the smear layer is removed. A powder liquid combinations, the most common of which is Grossmans sealer, contains small particles in the powder that could enter the orifices of the dentinal tubules and help create a reaction interface between sealer and canal wall.

→ $Ca(OH)_2$ based sealers have the advantage of promoting the apposition of cements at the canal apex and sealing it off against microleakage.

Post Cementation

→ Removal of smear layer increases cementum bond and the tensile strength of the cementing medium. GICs are effective in postcementation after smear layer removal because the glass ionomer has a better union with tooth structure.

→ With the removal of smear layer and an unfilled resin bonding agent, shorter posts can be used.

The smear layer

→ The advantages and disadvantages of smear layer and whether it should be removed or not from the instrumented tooth surface is still controversial. The risk of smear layer acting as a physical barrier to bacteria and its byproducts has been supported by many researchers.

→ Vejinovic et al showed that bacteria could not penetrate into dentin in the presence of smear layer. Conversely, Baker and others observed that bacteria could remain in the smear layer and in the dentinal tubule despite instrumentation of the root canal and thus may survive and multiply and can grow into dentinal tubules.

Methods of Removal

→ Brannstorm's group has published several articles describing the use of H2O, H2O2, benzalkonium chloride, EDTA and other agents to remove the smear layer. He has formulated several commercially available products like Tublicid Blue Label, Tublicid Red Label etc. that are designed to remove most of the smear layer without removing smear debris that has fallen into orifices of the tubules to form plugs on the cut surface of the dentin. Though this concept is ideal, it is difficult to achieve clinically because of the complex geometry of many cavities and the difficulty in obtaining adequate access.

1. Remove the smear layer by etching with acid. This seemingly extreme procedure does not injure the pulp, especially if dilute acids are used for short periods of time. Etching dentin with 6% citric acid for 60 seconds removes all of the smear layer as does 15 seconds of etching with 37% phosphoric acid.

The advantages are:

- The smear layer is entirely removed.
- The tubules are open and available for retention.
- The surface collagen is exposed for possible covalent linkages with new experimental primers for cavities.
- Further, with the smear layer gone, one doesn’t have to worry about it slowly dissolving under a leaking restoration or being removed by acid produced by bacteria, leaving a void between

the cavity wall and the restoration, which might permit bacterial colonization.

The disadvantages of removing the smear layer is that:

- In its absence, there is no physical barrier to bacterial penetration of dentinal tubules.

2. Another entirely different approach would be to use a resin that would infiltrate through the entire thickness of the smear layer and either bond to underlying matrix or penetrate into the tubules. The impressive tensile strengths recently obtained from Scotch Bond may be due to such a process.

3. To try to fix the smear layer by glutaraldehyde or tanning agents such as tannic acid or ferric chloride. The idea is to increase the cross linking of exposed collagen fibres within the smear layer and between it and the matrix of the underlying dentin to improve its cohesion.

4. A fourth and most recent approach to the problem is to remove the smear layer by etching with acid and replace it with an artificial smear layer composed by a crystalline precipitate.

   - Bowen has used this approach by treating dentin with 5% ferric oxalate which replaced the original smear layers with a new complex permitting extremely high bond strengths to be produced between restorations and dentin.

→ The quality of smear layer removed will vary with the type of solvent used.

NaOCl

→ The capacity of sodium hypochlorite to remove smear layer from the instrumented root canal wall has been found to be insufficient. Even the combination of sodium hypochlorite and H_2O_2 proved to be ineffective NaOCl cannot destroy bacteria within tubules closed by a smear layer covering.

Chelating Agents

→ The most common chelating solutions 10ml of 17% are based on ethylnediamine tetra acetic acid (EDTA) which reacts with Ca++ in dentin and forms soluble calcium chelates. While Fehr and Nygaard Ostby (1963) found that EDTA decalcified dentin to a depth of 20-30µm in 5 minutes, Fraser (1974) stated that chelating effect was almost negligible in the apical third of the root canals.

→ Different preparations of EDTA have been used as a root canal irrigant. Root canal preparations i.e. a mixture of EDTA and urea peroxide left a residue of this mixture after instrumentation. This may have disadvantages in the hermetic sealing of root canals.

→ The combination of EDTA and cetrimide a quartenary ammonium bromide left no smear layer except in the apical part of the canal.

→ Other root canal chelating agents are salvizol which is based on aminoquinaldinum diacetate and EDTAC i.e. EDTA and Cetavlon.

Glyoxide

→ Is an irrigating solution i.e. comprised of 10% urea peroxide (carbamide peroxide) in a vehicle of anhydrous glycerol. In 1961 Steward proposed glyoxide to be an effective adjunct to instrumentation for cleaning of the root canal.

→ It has greater solvent action that 3% H_2O_2.

→ It enhances root canal lubrication without softening the dentine.

Organic Acids

→ Citric acid removed smear layer better than many acids such as polyacrylic acid, lactic acid and phosphoric acid except-EDTA. Yamada et al in 1983 observed that the 25% citric acid NaOCl combination was not effective as 17% EDTA-NaOCl combination. Besides citric acid left precipitated crystals in the root canal which might be disadvantageous in the root canal obturation.

- With 50% lactic acid, the canal walls were generally clean, but the openings of the dentinal tubules did not appear completely patent.
- 25% tannic acid introduced by Bitter in 1989 was better than NaOCl – H2O2 combination.
- 20% polyacrylic acid was less effective than REDTA according to a study conducted by McCough and Smith.

Sodium hypochlorite and EDTA:

→ Goldman et al in 1982 have shown that the most effective working solution is 5-25% NaOCl and the most effective final flush was 10ml of 17% EDTA followed by 10ml of 5.25% NaOCl. NaOCl removes organic material including the collagenous matrix of dentin and EDTA removes the mineralized dentin, thereby exposing more collagen.

Ultrasonics

→ Used in conjunction with a solution of NaOCl can eliminate the smear layer. The apical region of the canal showed less debris and smear layer, than the coronal aspects, depending on the acoustic streams which was more intense in magnitude and velocity at the apical region of the file.

Conclusion

→ Our knowledge of the smear layer, its structure and function is rapidly growing and will influence all areas of clinical dentistry in the near future. Much more work needs to be done, but the promise of greater understanding of the smear layer should provide increased beneficial through improved dental therapy.

References

- Cohen.
- Ingle.
- Operative Dentistry, Supplement 3 1984, 1-12.