Smear Layer In Dentistry: A Review

[1]Dr. Divya Panday, [2]Dr. Monika Shrivastava, [3]Dr. Sanjana Bhargava, [4]Dr. Ami Rawal, [5]Dr. Nida Malik, [6]Dr. Nishant Choudhary, [7]Dr. Surendra Gujarkar

[1]*Consultant Endodontist, Jai Prakash District Hospital, Bhopal, India*
[2]*Consultant Prosthodontist, Dental Clinic, Delhi, India*
[3]*Consultant Pedodontist, Dental Clinic, Bhopal, India*
[4]*Reader, People's Dental Academy, People's University, Bhopal, India*
[5]*Consultant Periodontist, Dental Clinic, Bhopal, India*
[6]*Associate Professor, Department of Dermatology, Chirayu Medical College and Hospital, Bhopal, India*
[7]*Sai Oral and Dental Care, Bhopal, India*

Corresponding author: Dr. Nishant Choudhary,
drnic.89@outlook.com

ABSTRACT
The smear layer has been a topic of debate for decades. For a clinician, the smear layer may present various advantages and disadvantages. This further complicates the decision to retain it, remove it, or modify it. Clinical criteria like bond strength, micro-leakage, and discoloration of a restoration depend on the seal attained between tooth and restoration. This further depends on the smear layer treatment done prior to restoration. The smear layer affects sealer and filling material penetration in the root canal system. The success of root canal therapy depends on the presence or absence of the smear layer. The purpose of this article is to discuss the formation, composition, role, and removal of the smear layer, along with its effect on microleakage, sealer penetration, bacterial penetration, dentin permeability, bond strength, and deproteinization.
Keywords: Resin tags, smear layer, microleakage, dentin bonding, endodontics conservative dentistry restorative dentistry

Doi: 10.31838/ecb/2023.12.9.194

INTRODUCTION AND BACKGROUND

The smear layer, defined as a layer of organic and inorganic debris formed during cavity preparation or root canal instrumentation, has been an issue of intrigue and contemplation from the very beginning. It has both advantages and disadvantages, making it difficult for the endodontist to decide whether to retain or remove it. Different schools of thought have come up regarding the status of the smear layer. Cobankara argued that the smear layer is responsible for bacterial contamination and leakage between the root canal wall and filling material owing to its loosely adherent structure [1]. Conversely, Timpawat stated that smear layer serves as a barrier to prevent microleakage and bacterial penetration into the dentinal tubules [2]. A recent trend that is in favour of retention of the smear layer says that since no technique can completely remove the smear layer, its modification to a structure that is more stable and resistant to microleakage would be beneficial. According to Sen BH et al, agents such as potassium oxalate, 5% ferric oxalate, 4% titanium tetrafluoride, and self-etching primers have been tried in this regard[3]. Thus, newer trends aiming at modifying the structure of the smear layer are being researched to harness the beneficial effects of this mechanically and chemically interlocked, extremely stable layer, both in restorative dentistry and endodontics.The objective of this review article is to explore the literature on this subject so as to come to the conclusion that modification of the smear layer is viable or not. The smear layer has been studied by various researchers regarding its formation, composition, role, removal by different agents, its effect on microleakage, sealer and filling material penetration, bacterial penetration, bond strength, dentin permeability, and deproteinization. A review of the literature on the above has been discussed below.

REVIEW

FORMATION OF SMEAR LAYER

Since itwas initially observed, the smear layer has been a subject of discussion and speculative thinking.Boyde et al, who first noted the presence of this layer of detritus on the surface of sliced enamel, gave it the name "Smear Layer" and Mc Comb and Smith observed this layer on the walls of instrumented root canals [4, 5]. Instead of being uniformly sheared, the mineralized matrix that makes up the coronal smear layer is broken, creating a large amount of debris. The smear layer is sometimes compared to a clump of damp sawdust on a chopped log.

Actually, teeth fragments varying in size from less than 0.5µm to15 µm make up the smear layer. According to Pashley et al, these particles are similarly made up of globular subunits with a diameter of between 0.05 µm and 0.1 µm that came from mineralized fibres [6].

COMPOSITION OF SMEAR LAYER

There are both organic and inorganic components in the smear layer. Dentin, enamel, and a few unidentified elements make up the smear layer's inorganic components. The organic components consist of tissue from pulp and dentin, salivary constituents, charred proteins, microbes, and blood cells. The organic phase forms a matrix for the inorganic phase. Mader et alin a scanning electron microscope investigation, found that the smear layer consists of two confluent components: the superficial layer, which has an average thickness of 1-2µm, and the smear plugs, which are composed of dentin debris that has entered the orifices of dentinal tubules. The thickness of smear plugs varies from a few micrometres to 40µm[7].

The width of smear layer depends on various factors like wetness of dentin, type of bur, centrifugal force of instrument. Diamond bur produces greater amount of debris as compared to carbide bur. The root canal wall is covered with smear layer only after instrumentation during endodontic treatment, whereas uninstrumented canals are free of it. Also, filing combined with irrigant solution produces less smear layer as opposed to filing solely. The bend of the hand instrument also affects the debris collection. Straight file produces thicker smear layer than precurved file.

ROLE OF SMEAR LAYER

A resin-dentin interdiffusion zone or hybrid layer is formed when primer and bonding resin are applied to etched dentin. Resin tags are formed by penetration into open dentinal tubules and intertubular dentin. In etch-and-rinse adhesives, there is an abrupt transition between the hybrid layer and mineralized tissue of dentin, with no empty spaces or pathways that could result in leakage. The transition line seems to consist of hydroxyapatite crystals embedded in the resin from the hybrid layer. For self-etch adhesive systems, the gradation is progressive, with a superficial zone of resin-impregnated smear residues and a deeper zone rich in hydroxyapatite crystals.

In endodontics, there will be an accumulation of smear layer after instrumentation, collecting within the canal and pulp chamber. The microorganisms and their products found in the smear layer can provide a reservoir of potential irritants.A conflicting notion about the function of the smear layer in a restoration's sealing process was put out by Jodaikin and Austin. He postulated that the smear layer creates a setting that is favourable for the beginning and development of the sealing mechanism. The smear layer may also have a physical as well as a chemical role in margin sealing by preventing the dentinal fluid from draining the molecules that impacted the seal from the restoration-tooth interface [8].

MECHANISM OF SMEAR LAYER REMOVAL

Etch and rinse adhesives use a strong acid to completely etch enamel and dentin, followed by a water rinse to remove the acid from the tooth surface. The acid exposes the enamel prisms from the superficial hydroxyapatite layer and dislodges the smear layer. On dentin, the acid demineralizes the superficial hydroxyapatite and removes the smear layer and smear plugs (debris occluding the dentinal tubules) to expose the collagen fibrils of the dentinal matrix and open the dentinal tubules, funnelling their orifices. Self-etch adhesives contain acidic monomers to dissolve the smear layer on enamel and dentin. These adhesives increase the permeability of the smear layer to monomer penetration.

SMEAR LAYER REMOVAL BY VARIOUS AGENTS

It is not practically possible to remove the smear layer completely owing to the complicated architecture of many cavities[9]. In endodontics, various irrigating solutions have been tried in this regard, during and after instrumentation, to flush away the debris. Among the various chemical agents, the irrigants used for smear layer removal may be mentioned as proteolytic enzymes, normal saline, sodium hypochlorite, hydrogen peroxide, citric acid, lactic acid, polyacrylic acid, ethylene diamine tetraacetic acid, and sodium lauryl sulphate. A mixture of tetracycline and detergent (MTAD), oxidative potential water, tannic acid, and phosphoric acid in varying concentrations have also been used, although with conflicting results.

The most commonly used physiological saline as a root canal irrigant, accomplished gross debridement and lubrication action but failed to destroy the microbiological matter. When it is used alone, a residual layer of debris is formed, which obliterates the dentinal tubules. Hydrogen peroxide flushes were also found to be ineffective.Sodium hypochlorite dissolves the organic matrix through the release of hypochlorous acid. While 0.5% sodium hypochlorite left some fibrils, concentrations of 5.25%, 2.5%, and 1% entirely eliminated predentinand pulpal remains from the uninstrumented surfaces. Citric acid paired with sodium hypochlorite is a more potent irrigant than sodium hypochlorite alone for removing the smear layer off the surface of prepared root canals [10].

Glyoxide has been tried as a desirable adjunct to root canal irrigants since it is non-allergenic, non-irritating, and has detergent and haemostatic properties. Stewart et al showed that glyoxide, which is 10% carbamide peroxide combined with anhydrous glycerol, has greater bactericidal activity than 3% aqueous hydrogen peroxide[11]. Glyoxide used with sodium hypochlorite demonstrated increased dentinal particle removal as compared to sodium hypochlorite alone[12].

The most common chelating solutions used for removing the smear layer are based on ethylene diamine tetraacetic acid. Grossman et al found that ethylene diamine tetraacetic acid reacts with calcium ions in dentin to form soluble calcium chelates[13]. A quarternary ammonium bromide (cetrimide) has been added to ethylene diamine tetraacetic acid solutions to reduce surface tension and increase penetrability of the solution[14]. McComb and Smithreported that when this combination (REDTA) was used during instrumentation, there was no smear layer except in the apical part of the canal[4]. With the application of ethylene diamine tetraacetic acid with cetavelon (EDTA-C), Goldberg and Abramovich noted that the circumpulpal surface had a smooth structure and the dentinal tubules had a regular circular appearance. The most effective irrigating solution for eliminating the smear layer turned out to be REDTA[15].

The most potent working solution, as per Goldman et al, came out to be 5.25% sodium hypochlorite. However, the most efficient final rinse was found to be 10 ml of 17% ethylene diamine tetraacetic acid followed by 10 ml of 5.25% sodium hypochlorite, according to Goldman et al, which was also supported by Yamada et al[16,17].Combination of citric acid and sodium hypochlorite eliminated smear layer better than lone use of sodium hypochlorite[18,10]. In a research by Wayman et al, no smear layer was present in any of the canals cleaned with 10%, 25%, or 50% citric acid solutions. Though, the consecutive use of 10% citric acid solution and 2.5% sodium hypochlorite solution, ending with 10% citric acid solution was shown to be the most successful in removing the smear layer. Citric acid did, however, leave precipitated crystals in the root canal, which could be problematic for root canal obturation[19]. The smear layer is partially removed with weak acid, leaving behind smear plugs. Tannic acid, polyacrylic acid, and 0.04% ethylene diamine tetraacetic acid are mild enough to remove only the smear layer, leaving behind intact smear plugs.

Ghoddusi et al compared MTAD with EDTA and found that it takes longer for bacteria to penetrate when either EDTA or MTAD is used for smear layer removal [20]. De-Deus et al compared the demineralizing ability of 5% citric acid, BioPure MTAD, and 17% EDTA on radicular dentin and interpreted that the demineralization kinetics promoted by the former two were faster than the latter [21].

The application of ultrasound in endodontics was studied after the invention of ultrasonic equipment[22]. It was found that smear-free root canal surfaces were obtained after ultrasonically agitating the sodium hypochlorite solution. Cameronet alshowed that while concentrations of 2% to 4% sodium hypochlorite in combination with ultrasonic energy, were able to remove the smear layer, lower concentrations of the solution were unsatisfactory. On comparing the time duration for ultrasonic irrigation, they found that 3 minutes and 5 minutes removed the smear layer, however, 1 minute was ineffective[23].Contrary to these findings, other researchers also discovered that the smear layer could not be removed by ultrasonicdevices [24].Smear Clear, a 17% ethylenediaminetetraacetic acid (EDTA) solution with surfactants, and 17% EDTA, with and without the use of ultrasonics, were compared by Lui et al. for their in vitro performance in removing the smear layer. The use of ultrasonic instrument with 17% EDTA led to better smear layer removal in the canal's apical area [25].

MICROLEAKAGE

Microleakage of the root canal has been defined as the passage of bacteria, fluids, and chemical substances between the tooth and the filling material of the root canal. Leakage may occur at either the interface between the sealer and the canal wall or between the sealer and the gutta percha. The maximum leakage arises between the sealer and the root canals' wall, according to Hovel and and Dumsha's research [26].

The topic of microleakage in the root canal is complicated because a variety of factors, including root filling methods and the physical and chemical characteristics of sealers, which can affect leakage. Some researchers claimed that the smear layer's existence or absence had no discernible influence on the apical seal, while others claimed that its removal improved the obturation seal [27, 28]. According to Likhitkar et al, removing the smear layer increases resistance to microleakage [29]. The reverse was true according to a study by Timpawat et al, where in when the smear layer was removed, there was noticeably more apical microleakage than when it was left in place[2].

SEALER AND FILLING MATERIAL PENETRATION

The smear layer affects the adaptation of filling materials to the root canal walls and hence plays an important role in restorative dentistry and endodontics. Root canal sealers bond with the dentin by mechanical locking, except for glass ionomer cement, which bonds chemically.

Hence, in order to improve the retention of the filling material by the root canal walls, it has been proposed that the sealer plugs inside the dentinal tubules offer a mechanical interlocking. The formation of sealer plugs leads to an increased surface area, which improves the seal of the obturating material.The infiltration of gutta percha and sealer into the tubules is better when the smear layer is removed[30]. On the contrary, an in vivo study has demonstrated that the smear layer did not prevent the penetration of a Grossman type sealer into the dentinal tubules[31].
Thermo plasticized gutta-percha was shown to replicate a seal superior to that produced by lateral condensation. The smear layer removal improves the fluid-tight seal of the root canal system, whereas other factors, such as the obturation technique or the sealer, did not produce significant effects, according to a systematic review conducted by Shahravan et al [32].

BACTERIAL PENETRATION

The role of the smear layer as a physical barrier to bacteria and bacterial by-products has been supported by many researchers. Vojinovic et alshowed that dentinal plugs stopped bacterial invasion into dentinal tubules[33]. A study by Drake et al. indicated a reproducible order of magnitude difference ($p = 0.0002$) amongst teeth with smear layer (10^4colony-forming units) and teeth without (10^5 colony-forming units) when the quantity of bacteria was counted. According to one proposed mechanism, smear layer may prevent fluid and bacterial entrance into dentinal tubules by changing the permeability of the dentin.After canal preparation, any bacteria still present in the dentinal tubules may be sealed there by the smear layer and then by obturating materials [34]. Various authors reported that retaining the smear layer on the root canal walls may be beneficial in preventing bacterial penetration and colonisation [35-38].
Conversely, some authors observed that bacteria could remain in the smear layer and in the dentinal tubules despite instrumentation of the root canal, and thus they may survive, multiply, and grow into dentinal tubules. This showed that there are bacteria in the smeared layer and that they multiply and produce toxins that are harmful to the pulp [17,39-42]

DENTIN PERMEABILITY

Large molecules such as bacterial components and albumin can pass through the smear layer [37]. In addition, bacteria can propagate into dentinal tubules under restorations by degrading the smear layer formed after cavity preparation [40, 41, 43]. To some extent, dental professionals use sodium fluoride aqueous solutions (neutral or acidified), varnish, paste or gel to prevent the development of new cavities, lessen dentine hypersensitivity, and limit microleakage after cavity preparations. Prati et al conducted a study and showed that daily brushing with dentifrices may increase the risk of smear layer removal and induce dentin morphological modifications that can increase dentin permeability and sensitivity [44].
The titanium tetrafluoride surface treatment created a bulky layer that was more resistant to acidic or inorganic solutions than previous fluoride agents, according to the SEM investigation by Wefel and Harless[45]. Whereas Reed et al showed a caries-inhibiting effect of the topical application of titanium tetrafluoride on deciduous teeth after a period of 3 years, Buyukyilmaz et al observed in vivo retention of the titanium tetrafluoride coating on deciduous molars, with no new caries formation 15 months after the application [46, 47].

BOND STRENGTH

For restorative dentistry, the smear layer is either eliminated or modified to achieve a bond between the tooth and the restorative material [48]. The topography of the dentin surface after removal of the smear layer would reflect the coarseness of the abrasive, and coarser abrasives

would have an increased surface area, which in turn influences the bond strength of the adhesive agents [49].
Few authors showed no difference in bond strength of total-etch adhesive systems to different dentin smear layers, probably because these systems completely remove smeared debris from the surface[50]. It has been claimed that the self-etching primers have the capacity to penetrate dentin smears and impregnate the underlying dentin, most likely because of their inherent acidity[51]. Since the dissolved material is not rinsed away, the constituents of the smear layer are likely absorbed into the bonding layers [52].The bond strength of the self-etching agents is impacted by this hybridised smear layer, according to research by Koibuchi et al. [53].

DEPROTEINIZATION

The pre-treatment of dentin surfaces with deproteinizing agents does not enhance the bonding of self-etch adhesives to dentin. Sodium hypochlorite has a more detrimental effect on the bond strength of dentin as compared to hypochlorous acid. Two-step self-etch adhesives show more reliable bonding to deproteinized dentin than one-step self-etch adhesives. Long exposure to deproteinizing agents significantly impairs the bonding of self-etch agents to dentin [54].
Hosaka et al compared the bonding of self-etch adhesives to carious dentin and normal dentin. They found that deproteinization is more effective for caries-affected dentin because it has more organic content in the smear layer. Smear layer deproteinization with HOCl solution, which has rapid and broad-spectrum antimicrobial activity with less irritating and sensitising properties, along with the subsequent application of antioxidant and reducing agents, could enhance the longevity of composite restoration with self-etch adhesives [55].

DISCUSSION

If one were to simply conclude a discussion of the smear layer in terms of whether to remove, retain, or further modify it, it would be an injustice to a controversy that has intrigued many authors for decades. Its retention does compromise gutta percha adaptation to the root canal wall, increases susceptibility to bacterial irritation, decreases retention of cemented posts, and also increases the chances of apical leakage, but it is well known that teeth that are obturated with the smear layer intact show around a 90% success rate. When the smear layer is modified using certain chemicals, it achieves a stronger mechanical and chemical union with the root canal sealer that proves favourable in the long run.
In endodontics, this stable modified smear layer decreases the chances of reinfection by blocking dentinal tubules and increases microleakage resistance by preventing its disintegration. Since smeared dentine surfaces are modified to a stable and acid-resistant state, clinical use of acidic titanium tetrafluoride solutions in dentine cavities may be considered in restorative dentistry. The high interactivity of this acidic solution with dental hard tissues may be advantageous in reducing microleakage. Fluorides, which are readily taken up by enamel, dentin, and root surfaces, lead to decreased solubility of dentine and root surfaces.
Then we have self-etching primers, which use the smear layer as a bonding substrate. In case of self-etching primers, the bonding occurs through smear layer. The treated dentin is subsequently covered with an adhesive resin layer without any additional rinsing.The smear layer is intended to be incorporated into the hybrid layer.Collapse of air-dried, demineralized collagen is avoided because the smear layer-retained dentin is concurrently demineralized and polymerized in situ.Despite the insufficient depth of resin tags, a sufficient seal is still achieved since the smear plugs are left intact. Dentinal fluid transudation reduces the adhesive's susceptibility to moisture contamination.All these factors lead to enhancement of

the bond strength under the pulp horns, as compared to etch and rinse technique where the smear layer is completely eliminated.

Also, condipriming systems, which are generally less technique sensitive as compared to total etch systems, should be considered if there are chances that conventional etching, rinsing, drying, and bonding steps would cause intensive hydrodynamic effects in hypersensitive dentin, including chemically eroded dentin. A2 μm thick smear layer is penetrated by demineralizing the dentin and engaging the underlying intact dentin to a reasonable depth. Since the intratubular plugs are retained and the superficial smear layer removed, this allows for better adaptation of the restorative material to the cavity walls and, at the same time, prevents the ingress of bacteria.

CONCLUSION

As a conclusion, newer trends should be aimed at modifying the smear layer for a myriad of reasons, like better adaptation of filling materials (be it in the root canal or coronal cavities), reduced microleakage, prevention of bacterial invasion, pulpal protection, reduced dentinal hypersensitivity, and of course increased bond strength. Research in this area is still ongoing to further discover its effects in clinical practise, but till date, whatever has been done to analyse the status of this tenacious, extremely adherent modified smear layer has shown promising results, both in restorative dentistry and endodontia.

REFERENCES

1. Cobankara FK, Adanir N, Belli S. Evaluation of the influence of smear layer on the apical and coronal sealing ability of two sealers. J Endod 2004; 20(6): 406-409.
2. Timpawat S, Vongsavan N, Messer HH. Effect of removal of the smear layer on apical microleakage. J Endod 2001; 27(5):351-353.
3. Sen BH, Buyukyilmaz T. The effect of 4% titanium tetrafluoride solution on root canal walls – a preliminary investigation. J Endod 1998; 24(4):239-243.
4. McComb D, Smith DC. A preliminary scanning electron microscopic study of root canals after endodontic procedures. J Endod 1975; 1: 238-242.
5. Sen BH, Wesselink PR and Turkun M. The smear layer: a phenomenon in root canal therapy. Int Endod J 1995; 28: 141-148.
6. Pashley DH, Tao L, Boyd L, King GE, Horner JA. Scanning electron microscopy of the substructure of smear layers in human dentine. Arch Oral Bio 1988; 33: 265-270.
7. Mader CL, Baumgartner C, Peters DD. Scanning electron microscopic investigation of the smeared layer on root canal walls. J Endod 1984; 10(1): 477-483.
8. Jodaikin A, Austin JC. The effects of cavity smear layer removal on experimental marginal leakage around amalgam restorations. J Dent Res 1981; 60: 1861-1866.
9. Pashley DH. The smear layer: physiological considerations. Operative Dentistry Suppl 1984; 3: 13-29.
10. Baumgartner JC, Brown CM, Ader CL et al. A scanning electron microscopic evaluation of root canal debridement using saline, sodium hypochlorite and citric acid. J Endod 1984; 10: 525-531.
11. Stewart GG, Cobe HM, Rappaport H. A study of new medicament in the chemicomechanical preparation of infected root canal. JADA 1961; 63: 153-157.
12. Rome WJ, Doran JE, Walker WA. The effectiveness of Gly-oxide and NaOCl in preventing smear layer formation. J Endod 1985; 11(7): 281-288.
13. Grossman LI, Oliet S, Delrio CE. Endodontic practice Philadelphia. Lea and Febiger. 11th edition, 1988.
14. Fehr FR, Nygaard-Ostby B. Effect of EDTAC and sulphuric acid on root canal dentin. Oral Surg Oral Med Oral Path 1963; 16: 199-205.
15. Goldberg DB, Abramovich A. Analysis of effect of EDTAC on dentinal walls of root canal. J Endod 1977; 3: 101-105.
16. Goldman M, Goldman LB, Cavaleri R, Bogis J, Lin PS. The efficacy of several irrigating solutions for endodontics: A scanning electron microscopic study: Part 2. J Endod 1982; 8: 487-492.
17. Yamada RS, Armas A, Goldman M, Lin PS. A scanning electron microscopic comparison of a high volume final flush with several irrigating solutions. J Endod 1983; 9: 137-142.
18. Loel D. Use of acid cleanser in endodontic therapy. JADA 1975; 90: 148-155.
19. Wayman BE, Kopp WM, Pinero GJ, Lazzari EP. Citric and lactic acids as root canal irrigants in vitro. J Endod 1979; 5(9): 258-265.

20. Ghoddusi J, Rohani A, Rashed T, Ghaziani P, Akbari M. An evaluation of microbial leakage after using MTAD as a final irrigation. Journal of Endodontics. 2007 Feb 1;33(2):173-6.
21. De-Deus G, Reis C, Fidel S, Fidel R, Paciornik S. Dentin demineralization when subjected to BioPure MTAD: a longitudinal and quantitative assessment. Journal of endodontics. 2007 Nov 1;33(11):1364-8.
22. Martin H, Cunningham MJ, Norris JP, Cotton WR. Ultrasonic versus hand filling of dentin: A quantitative study. Oral Surg Oral Med Oral Path 1980; 49: 79-81.
23. Cameron JA. The use of ultrasonics in the removal of the smear layer: A scanning electron microscope study. J Endod 1988; 9(7): 289-292.
24. Cymerman JJ, Jerome LA, Moodnik RM. A scanning electron microscope study comparing the efficacy of hand instrumentation of the root canal. J Endod 1983; 9: 327-331.
25. Lui JN, Kuah HG, Chen NN. Effect of EDTA with and without surfactants or ultrasonics on removal of smear layer. Journal of endodontics. 2007 Apr 1;33(4):472-5.
26. Hovland EJ, DUMSHA TC. Leakage evaluation in vitro of the root canal sealer cement Sealapex. International Endodontic Journal. 1985 Jul;18(3):179-82.
27. Madison S and Krell KV. Comparison of EDTA and NaOCl on the apical seal of endodontically treated teeth. J Endod 1984; 10 (10): 499-503.
28. Cergneux M, Ciucchi B, Dietschi BB, Holz J. The influence of the smear layer on the smear layer on the sealing ability of canal obturation. Int Endod J 1987; 20: 228-232.
29. Likhitkar MS, Kulkarni SV, Burande A, Solanke V, Kumar CS, Kamble B. To evaluate the influence of smear layer with different instruments and obturation methods on microleakage of root canal filled teeth: In vitro study. Journal of International Society of Preventive & Community Dentistry. 2016 May;6(3):240.
30. White RR, Goldman M, Lin PS. The influence of the smeared layer upon dentinal tubule penetration by plastic filling materials. J Endod 1984; 10: 558-562.
31. Vassiliadis LP, Skalvounos SA, Stavrianos DK. Depth of penetration and appearance of Grossman sealer in the dentinal tubules: an in vivo study. J Endod 1994; 20: 373-376.
32. Shahravan A, Haghdoost AA, Adl A, Rahimi H, Shadifar F. Effect of smear layer on sealing ability of canal obturation: a systematic review and meta-analysis. Journal of endodontics. 2007 Feb 1;33(2):96-105.
33. Vojinovic O, Nyborgh H, Brannstrom M. Acid treatment of cavities under resin fillings: Bacterial growth in dentinal tubules and pulpal reactions. J Dent Res 1973; 52: 1189-1193.
34. Drake DR, Wiemann AH, Rivera EM et al. Bacterial retention in canal walls in vitro: effect of smear layer. J Endod 1994; 20: 78-82.
35. Michelich V, Schuster GS, Pashley DH. Bacterial penetration of human dentin, in vitro. J Dent Res 1980; 59: 1398-1404.
36. Pashley DH, Michelich V, Kehl t. Dentin Permeability: effects of smeared layer removal. J Prosthet Dent 1981; 46: 531-537.
37. Pashley DH, Livingston MJ, Greenhill JD. Regional resistances to fluid flow in human dentin in vitro. Arch Oral Biol 1978; 23: 807-810.
38. Saleh IM, Ruyter IE, Haapasalo M, Ørstavik D. Bacterial penetration along different root canal filling materials in the presence or absence of smear layer. International Endodontic Journal. 2008 Jan;41(1):32-40.
39. Baker NA, Eleazer PD, Avergace RE, Seltzer S. Scanning electron microscopic study of the efficacy of various irrigating solutions. J Endod 1975; 1: 127-135.
40. Brannstrom M, Nyborg H. Cavity treatment with a microbial fluoride solution: growth of bacteria and effect on the pulp. J Prosthet Dent 1973; 30: 303-310.
41. Olgart L, Brannstrom M, Johnson G. Invasion of bacteria into dentinal tubules. Experiments in vivo and in vitro. Acta Odon Scand 1974; 32: 391-395.
42. Brannstrom M, Nyborg H. Bacterial growth and pulpal changes under inlays cemented with zinc phosphate and epoxylate CBA 9080. J Prosthet Dent 1974; 31: 556-565.
43. Meryon SD, Brook AM. Penetration of dentine by three oral bacteria in vitro and their associated toxicity. Int Endod J 1990; 23: 196-202.
44. Prati C, Venturi L, Valdre G, Mongiorgi R. Dentin morphology and permeability after brushing with different toothpastes in the presence and absence of smear layer. J Periodontol 2002; 73(2):183-190.
45. Wefel JS, Harless JD. The effect of topical fluoride agents on fluoride uptake and surface morphology. J Dent Res 1981; 60: 1842-1848.
46. Reed AJ, Bibby BG. Preliminary report on effect of topical aplications of titanium tetrafluoride on dental caries. J Dent Res 1976; 55: 357-358.
47. Büyükyilmaz T, Sen BH, Øgaard B. Retention of titanium tetrafluoride (TiF4), used as fissure sealant on human deciduous molars. Acta Odontologica Scandinavica. 1997 Jan 1;55(2):73-8.
48. Swift Jr EJ, Perdigao J, Heymann HO. Bonding to enamel and dentin: a brief history and state of the art. Quint Int 1995; 26 (2): 95-110.

49. Ayad MF, Rosenstiel SF, Hassan MM. Surface roughness of dentin after tooth preparation with different rotary instrumentation. J Prosthet Dent 1996; 75 (2): 122-128.
50. Tao L, Pashley DH. Effect of different type of smear layers on dentin and enamel shear bond strength. Dent Mater 1988; 4: 208-216.
51. Nakabayashi N, Saimi Y. Bonding to intact dentin. J Dent Res 1996; 75 (9): 1706-1715.
52. Tay FR, Pashley DH. Aggressiveness of contemporary self etching system. I: Depth of penetration beyond dentin smear layers. Dent Mater 2001; 17(4): 296-308.
53. Koibuchi H, Yasuda N, Nakabayashi N. Bonding to dentin with a self-etching primer: the effect of smear layers. Dental Materials. 2001 Mar 1; 17(2):122-6.
54. Alshaikh KH, Hamama HH, Mahmoud SH. Effect of smear layer deproteinization on bonding of self-etch adhesives to dentin: a systematic review and meta-analysis. Restorative Dentistry & Endodontics. 2018 Mar 6;43(2).
55. Hosaka K, Prasansuttiporn T, Thanatvarakorn O et al. Smear layer-deproteinization: improving the adhesion of self-etch adhesive systems to caries-affected dentin. Current Oral Health Reports. 2018 Sep; 5:169-77.