



EFFECTIVENESS OF 17% EDTA ON THE SMEAR LAYER REMOVAL IN ROOT CANALS OF HUMAN TEETH –A SYSTEMATIC REVIEW

Dr. Sharon Coelho^{*1}, Dr. Rajesh Shetty², Dr. Devashish Solapurkar³, Dr. Sailee Ghare⁴, Dr. Mubssira Shaikh⁵
Dr. Neha Neekhara⁶

^{1,3,4,5,6}P. G. Scholar, Department of Conservative Dentistry and Endodontics, Dr. D. Y. Patil Vidyapeeth, Pune 411018.
²Professor and Guide, Department of Conservative Dentistry and Endodontics, Dr. D. Y. Patil Vidyapeeth, Pune 411018.

*Corresponding Author: Dr. Sharon Coelho

P. G. Scholar, Department of Conservative Dentistry and Endodontics, Dr. D. Y. Patil Vidyapeeth, Pune 411018.

Article Received on 22/08/2017

Article Revised on 12/09/2017

Article Accepted on 03/10/2017

ABSTRACT

Background: The removal of smear layer is necessary to achieve disinfection of the root canal system by deeper penetration of the root canal medicaments and irrigants. Various agents including organic acids, chelating agents, ultrasonics, and lasers have been used to remove the smear layer. Of these, the chelating agent ethylene diamine tetra-acetic acid (EDTA) in its different physical forms and formulations is most commonly used for smear layer removal; however, the search continues for newer and better agents. **Objectives:** The aim of this study was to systematically gather and evaluate the effectiveness of 17% EDTA for the removal of smear layer in root canals of human extracted teeth. **Data Sources:** A systematic search was conducted using MEDLINE, Google Scholar, Google and manual search using DPU College library resources upto 31st December 2015 to identify appropriate studies. All cross reference lists of the selected studies were also screened. Two reviewers assessed the eligibility of studies. **Study eligibility criteria:** In vitro and Comparative studies were selected; however, only articles where the effect of 17% EDTA on smear removal in root canals of freshly extracted human teeth were included. Review, case reports, abstracts, letters to editors, editorials were excluded. In vivo studies were excluded. **Participants:** Participants were comprised of freshly extracted human teeth. **Interventions:** Samples were subjected to 17% EDTA in all the studies. **Results:** 1817 articles from PubMed search was found relevant according to the inclusion criteria. An addition of 4 articles was included from other sources. A total of 31 records were screened according to title and selected. A final of 8 articles have been used for detailed evaluation in this systematic review after assessment of full text. 3 of these articles show similar efficacy of the respective irrigants used. In 5 studies 17% EDTA was effective in smear layer removal. **Limitations:** These studies do not give concrete conclusions due to an inadequate search of the literature because of less access to search forums, failure to evaluate the quality of studies, failure to exclude poorly designed studies, inappropriately combining heterogeneous studies, smaller sample sizes, availability of relevant articles in different languages other than English. **Conclusion:** 17% EDTA is effective for smear layer removal in root canals in human extracted teeth especially in cervical and middle third. But on increasing the duration of application it causes erosion of human dentin.

KEYWORDS: 17% EDTA, smear layer, root canal, chelating agent, systematic review.

INTRODUCTION

Root canal therapy cleans the root canal system through mechanical instrumentation and root canal irrigation^[1]. However during the process of instrumentation, large amount of dentin debris mix with vital and necrotic remnants of pulp tissue, in combination with microorganisms and microbial toxins adhered to the root canal wall, form a *smear layer*.^[2]

This smear layer prevents medicaments from penetrating into the dentinal tubules and killing the bacteria from within. In addition, the smear layer also decreases the

adaptability of filling materials and their penetration into the canal walls, thus reducing their sealing ability.^[2,3]

Studies have demonstrated that a large proportion of root canal walls remain untouched after mechanical preparation.^[4,5] emphasizing the essential role of irrigation in endodontic procedures. Irrigation can improve the removal of bacteria, necrotic pulp tissue, debris, and smear layer in combination with mechanical root canal instrumentation.^[6]

The literature recommends the use of irrigant solutions combined with chelating and demineralizing agents with the purpose of removing the organic and inorganic components of the smear layer, increasing the chances of successful endodontic therapy.^[7,8]

The use of ethylenediamine tetra-acetic acid (EDTA), a chelating agent is usually recommended to remove the smear layer.

This substance is a weak acid with chelating action and concomitant protein denaturing^[9] which promotes the increase in dental permeability facilitating the action of the intracanal medication^[10] and the bond between dentin and endodontic cements^[11], in addition to being biocompatible.^[12]

EDTA has been widely used to dissolve the mineral phase of dentin while avoiding major alterations of the native fibrillar structure of the collagen in dentin.^[13,14]

Cederlund et al reported that an EDTA treatment increased immediate shear bond strength^[15] Sauro et al also reported that conditioning of the smear layers with EDTA produced a less porous resin-dentin interface.^[16]

Systematic reviews aim to find as much as possible of the research relevant to the particular research questions, and use explicit methods to identify, select, evaluate and analyze what can reliably be concluded on the basis of these studies. In this way, systematic reviews reduce the bias which can occur in other approaches to reviewing research evidence.

Previous in vitro experimental models have reported that an EDTA treatment of the dentin surface has a favorable effect on the resin-dentin bond. Nevertheless, there are few reports on the effect of 17% EDTA on the smear layer removal in root canals.

Therefore, the aim of this study was to review findings on the effects of 17% EDTA on smear layer removal in root canals using systematic review.

Focused Question

What is the effectiveness of 17% EDTA for the removal of smear layer in root canals of extracted human teeth using in vitro studies?

OBJECTIVES

To assess the literature regarding effectiveness of 17%EDTA for the removal of smear layer.

Eligibility Criteria

Inclusion Criteria

- Articles in English or those having detailed summary in English were included.

- Studies published between 1st January 2005 to 31st December 2015 were included.
- In vitro studies were included.
- Studies in which setting was laboratory based were included.
- Studies in which human dentin were used as samples were included.
- Studies in which 17% EDTA was used as intervention were included.
- Studies which provide information about smear layer removal using scanning electron microscope were included.

Exclusion Criteria

- Review, case reports, abstracts, letters to editors and editorials were excluded.
- In vivo and ex vivo studies were excluded.

The PICOS guidelines that were selected are

P where Participants were included and this comprised of freshly extracted human teeth. I as the Intervention where this was considered as use of 17%EDTA. O as the outcome where it was assessed as the removal of smear layer in root canal. S as the study designs were included in vitro studies.

And hence the PICOS are mentioned below:

P-Participants: Freshly extracted human teeth.

I-Intervention: Use of 17% EDTA.

O-Outcomes: Removal of smear layer.

S-Study design: In vitro studies.

Information Sources

The databases searched were PubMed and Google Scholar. Prospective studies were selected towards the efficacy of 17% EDTA for smear layer removal in root canals. English-language articles were retrieved from electronic biomedical journal databases and hand searching records.

Search

The following databases were searched on January 1st, 2005: PubMed (without filter, from 2005 to December 31st, 2015) and Google Scholar. For the electronic search strategy, the following terms were used as keywords in several combinations.

Table 1: Table showing keywords used in this systematic review.

1. Ethylenediamine tetra-acetic acid	Dentin pretreatment agents OR chelating agents OR citric acid OR phosphoric acid
2. Smear layer	Debris OR biofilm

Table 2: Table representing number of articles established using search strategy.

Sr. No.	Search strategy	Number of articles	Number of selected articles	After Duplicate Removal
LD1	EDTA AND Smear layer OR Biofilm removal	162	15	4
LD2	EDTA OR Chelating agents AND Smear layer OR Biofilm removal	193	22	3
LD3	Smear layer removal AND Chelating agents OR EDTA	1462	25	4
Other sources		4	4	0
Total		1821	62	31

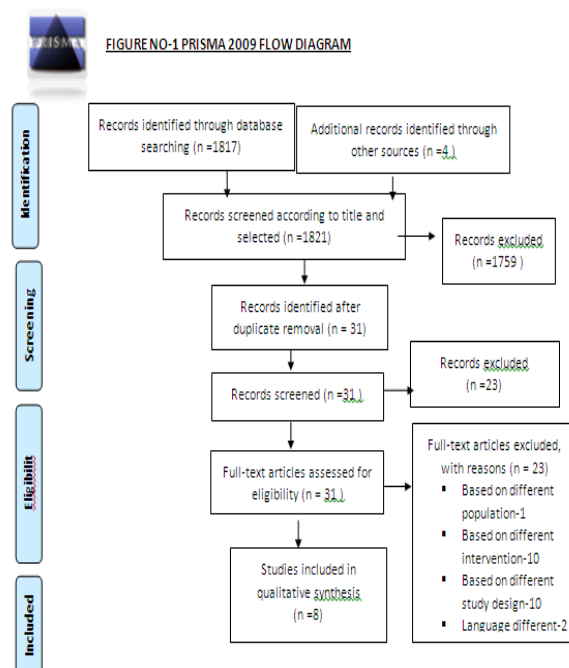
Summary of Evidence

Several reviews may have been studied to assess the effectiveness of 17% EDTA on smear layer removal in root canals in human extracted teeth at different time intervals. This systematic review has been attempted to find the best available evidence for the same. However, it is difficult to draw conclusions from the articles selected as they cannot be compared directly due to the diversity of eligibility criteria's, assessment methods and outcomes.

Eight studies met the inclusion criteria established for the present investigation.

Ana Carolina et al. in 2003 carried out a study using scanning electron microscopic (SEM) to analyze the cleaning qualities and smear layer removal from root canal walls, instrumented and irrigated with 2.5% NaOCl, 2.0% chlorhexidine and saline solutions. Fifty 8extracted teeth were used in this study. All teeth were radiographed to determine the existence of a single canal. The crowns were cut at the cervical limit and the root canals were instrumented with K-type files up to size 45. During root canal preparation, irrigations were made with the different solutions being evaluated: Group 1: 2.5% NaOCl (10 roots); Group 2: 2.5% NaOCl and 17% EDTA for 2 minute (10 roots); Group 3: 2.0% chlorhexidine (10 roots); Group 4: 2.0% chlorhexidine and 17% EDTA for 2 minutes (10 roots); Group 5: saline solution (5 roots); Group 6: saline solution and 17% EDTA for 2 minutes (5 roots). After instrumentation, the canals were irrigated with each one of the solutions and the roots were cut in the buccolingual direction for SEM analysis, at the cervical, middle and apical thirds, to ascertain the presence or absence of smear layer and debris. SEM analysis was performed by three calibrated examiners and scores were submitted to Kruskal-Wallis test at the significance level of $p = 5\%$. Results showed that the use of 17% EDTA decreased the smear layer significantly ($p < 0.05$) for all evaluated solutions in all thirds. When EDTA was not used, a significantly higher quantity of smear layer on the apical third was observed only in the NaOCl groups. The use of 17% EDTA was significant for debris removal except for the chlorhexidine groups. The following conclusion was

drawn that the use of 17% EDTA was necessary to enhance cleanliness of the root canals.^[17]



Wadhvani KK et al. in 2011 conducted a study to evaluate the ability of 17% ethylenediaminetetraacetic acid (EDTA) solution and 19% EDTA gel to remove debris, and smear layer produced during root canal preparation with two NiTi files systems, Mtwo and Protaper. Twenty freshly extracted human anterior teeth with single root canal were collected. The crowns were sectioned at the cemento-enamel junction, and working length was measured. These samples were randomly divided into four groups of five samples each. In each group, 2 ml of 3 % sodium hypochlorite solution was used with first instrument. The groupings were as follows. Group 1: 2 ml of 17% EDTA solution and 2 ml of 3% NaOCl were used alternatively each time a new file was employed. This group was prepared with Mtwo rotary files. Group 2: The samples in this group was prepared with Mtwo rotary files. EDTA gel (19%) was used and the samples were irrigated with 2 ml of 3% NaOCl. NaOCl and EDTA gel were used alternatively. Group 3: Five samples were prepared with Protaper file.

Irrigation regime was the same as in Group 1. Group 4: Five samples were prepared with Protaper files and irrigation regime was the same as in Group 2. SEM study was done and the collected data were submitted for statistical analysis. The results obtained by them was that no statistically significant difference with the varied instruments used (Mtwo and Protaper files), and 17% EDTA solution and 19% EDTA gel.^[18]

Dadresanfar B et al. in 2011 conducted a study to compare the effects of ultrasonication with ethylenediaminetetraacetic acid (EDTA) and a mixture of tetracycline isomer, an acid, and a detergent (MTAD) as final canal irrigants on the smear layer, debris and erosion scores. Fifty-eight extracted single-rooted human teeth were instrumented with ProTaper rotary files up to size F3. According to the final irrigation regimen, the samples were distributed into the following groups: EDTA, MTAD, EDTA ultrasonicated for 1 min, and MTAD ultrasonicated for 1 min. The smear layer, debris and erosion scores were recorded at the apical, middle, and coronal third of each canal using a scanning electron microscope. Data were subjected to statistical evaluation using the Kruskal-Wallis and Mann-Whitney tests ($P < 0.05$). There were no significant differences in smear layer or debris removal between the experimental groups. EDTA caused significantly more erosion at the middle level than MTAD. Also EDTA resulted in more erosion at the coronal level than MTAD when subjected to ultrasonication. Ultrasonic activation of EDTA significantly increased its erosive effects at the middle and coronal levels. Based on the present findings, MTAD appears to cause less dentinal erosion while allowing proper removal of the smear layer and debris.^[19]

Maira Prado et al. in 2011 stated that the smear layer adheres to dentinal surface, thus occluding the dentinal tubules. Because this layer disfavors the penetration of irrigant solutions and root canal fillings, it should be removed. They conducted a study to compare the effectiveness of 37% phosphoric acid with that of 17% EDTA and 10% citric acid in the removal of smear layer.

In their study fifty-two maxillary single-rooted human canines were accessed and instrumented. Between each instrument used, the canals were irrigated with sodium hypochlorite. After instrumentation, the teeth were irrigated with distilled water and then divided into groups according to the time and substances employed. The substances used were 17% EDTA, 10% citric acid, and 37% phosphoric acid solution and gel. The experimental time periods were of 30 seconds, 1 minute, and 3 minutes. The samples were prepared and observed by means of scanning electron microscopy. Three photomicrographs (2,000 \times) were recorded for each sample regarding the apical, middle, and cervical thirds. A score system was used to evaluate the images. The results obtained by them were that none of the substances analyzed in this study were effective for removing the

smear layer at 30 seconds. In the 1-minute period, the phosphoric acid solution showed better results than the other substances evaluated. In the 3-minute period, all the substances worked well in the middle and cervical thirds although phosphoric acid solution showed excellent results even in the apical third. These findings point toward the possibility that phosphoric acid solution could be a promising agent for smear layer removal.^[20]

Xiaofei Zhu et al. in 2013 stated that the Er:YAG laser with photon-induced photoacoustic streaming (PIPS) technique was reported to be effective in root canal disinfection. They conducted a study to further investigate the antibacterial efficacy and smear layer removal ability of PIPS in comparison with conventional syringe irrigation *in vitro*. For antibacterial analysis, 48 single-rooted human teeth were prepared and inoculated with *Enterococcus faecalis*, and then divided into six groups of eight roots each. The colony-forming units (CFUs) per milliliter were determined after infection as the baseline. Then, the teeth were subjected to either PIPS plus 3% sodium hypochlorite (PIPS + NaOCl) or conventional syringe irrigation with 0.9% saline, 3% NaOCl, 17% ethylenediaminetetraacetic acid (EDTA), 0.2% chlorhexidine gluconate (CHX), or 3% NaOCl alternating with 17% EDTA. The reduction of CFUs in the individual group was determined. Additionally, scanning electron microscopy (SEM) examination of the canal walls for *E. faecalis* colonization was performed. For comparing the smear removal efficacy, another 48 single-rooted teeth, assigned to different groups were irrigated after mechanical instrumentation. The presence of a smear layer at different levels of the root canal was scored by SEM examination. No significant differences were found in CFU reduction. No bacteria could be observed by SEM in the NaOCl, NaOCl + EDTA, and PIPS + NaOCl groups. The scores of smear layer of the NaOCl + EDTA and PIPS + NaOCl groups were significantly lower than those of the other groups in the coronal and middle third of the root canal. None of the methods could effectively remove smear layer in the apical third. Their study concluded that PIPS system supplied with NaOCl and conventional syringe irrigation with NaOCl + EDTA are comparable in their ability to remove *E. faecalis* and smear layer in single-rooted canals.^[21]

Eleni Protogerou et al. in 2014 evaluated the effectiveness of a highly flexible endodontic brush made of polypropylene canal brush (CanalBrush; Coltène) on smear layer removal from the canal walls when used according to the manufacturer's recommendations. Forty-four single-rooted mandibular incisors were prepared to apical size 30/0.06 and randomly divided into three groups A, B and C, where the final irrigation regimen was 10 mL 17% EDTA and 10 mL 2.5% NaOCl for group A, 10 mL EDTA, 5 mL NaOCl, CanalBrush for 20 s at 450 rpm and 5 mL NaOCl for group B, 10 mL NaOCl, CanalBrush and 10 mL NaOCl for group C. One medium-sized CanalBrush was used for each root canal

and all brushes were examined under the optical microscope after application to evaluate bristle deformation. Afterwards, roots were split longitudinally and the presence of smear layer was evaluated under a scanning electron microscope. Used brushes invariably exhibited bristle deformation. Group C exhibited the highest means of smear layer in all thirds. Comparing the apical thirds in all groups, there was no statistical difference between groups A and B (3.64 ± 0.48 and 3.68 ± 0.62 respectively), while group C exhibited significantly higher scores (3.9 ± 0.28) than the other two groups. In conclusion, the CanalBrush proved unable to remove smear layer from the instrumented root canals, when used according to the manufacturers' instructions.^[22]

Kirchhoff AL et al. in 2014 stated that the action of endodontic instruments during biomechanical preparation results in smear layer formation. Removing the smear layer enhances disinfection into dentinal tubules in addition to allowing tridimensional sealing of the root canal system. They conducted a study that was designed to evaluate the smear layer removal and quantify the calcium ion release resulting from final irrigation with different chelating solutions. Fifty human canines were instrumented and the final irrigation was performed with apple vinegar, 5% malic acid, 5% acetic acid, 17% ethylenediamine tetra-acetic acid (EDTA), and distilled water (control), which were collected and analyzed by atomic absorption spectrometry to quantify the concentration of calcium ions released. Smear layer removal was assessed in the cervical, middle, and apical thirds by SEM. There was statistically significant difference ($P < 0.001$) between 17% EDTA and the other solutions with regard to smear layer removal. Apple vinegar, 5% malic acid, and 5% acetic acid promoted similar root canal cleaning. There was no statistical difference among the root canal thirds. The highest concentrations of calcium ions were obtained with 17% EDTA ($P < 0.001$) followed by malic acid, apple vinegar, and acetic acid. Apple vinegar and acetic acid removed the smallest quantity of calcium ions. It was concluded that 17% EDTA enabled greater smear layer removal and promoted release of the highest concentrations of calcium ions than the other solutions tested.^[23]

Xiangjun Guo et al. in 2014 stated that efforts to improve the efficacy of smear layer removal by applying irrigant activation at the final irrigation or by elevating the temperature of the irrigant have been reported. However, the combination of such activation protocols with 60°C 3% sodium hypochlorite (NaOCl) has seldom been mentioned. Hence the aim of their study was to compare the efficacy in smear layer removal of four different irrigation techniques combined with 60°C 3% NaOCl and 17% EDTA. In their study fifty single-rooted teeth were randomly divided into five groups ($n = 10$) according to the irrigant agitation protocols used during chemomechanical preparation: a side-vented needle group, a ultrasonic irrigation (UI) group, a NaviTip FX

group, an EndoActivator group, and a control group (no agitation). After each instrumentation, the root canals were irrigated with 1 mL of 3% NaOCl at 60°C for 1 minute, and after the whole instrumentation, the root canals were rinsed with 1 mL of 17% EDTA for 1 minute. Both NaOCl and EDTA were activated with one of the five irrigation protocols. The efficacy of smear layer removal was scored at the apical, middle and coronal thirds. The Data were statistically analyzed using SAS version 9.2 for Windows (rank sum test for a randomised block design and ANOVA). Results obtained by them were that no significant differences among the NaviTip FX group, EndoActivator group and control groups, and each of these groups showed a lower score than that of UI group ($P < 0.05$). Within each group, all three thirds were ranked in the following order: coronal > middle > apical ($P < 0.05$). In the coronal third, the NaviTip FX group was better than UI group. In the middle and apical third, the differences were not significant among any of the groups. They concluded that even without any activation, the combination of 60°C 3% NaOCl and 17% EDTA could remove the smear layer effectively, similar to NaviTip FX or EndoActivator, and these three protocols were more effective than UI. However, regardless of different types of irrigation technique applied, complete removal of the smear layer was not achieved, particularly in the apical third.^[24]

LIMITATIONS

- This study did not give concrete conclusions due to inadequate search of literature because of less access to search forums.
- Failure to evaluate the quality of studies.
- Failure to exclude poorly designed studies.
- Small sample size.
- Availability of relevant articles in different languages other than English.
- Inappropriately combining heterogeneous studies due to different populations, settings, intervention and outcomes measures.

CONCLUSION

Keeping in mind the limitations of this review it can be concluded that 17% EDTA was effective in removal of smear layer from the cervical and middle thirds of root canals in human teeth. But on increasing the duration of application it caused erosion of dentin. This review also suggests that the action of EDTA is enhanced on using it in combination with sodium hypochlorite, as EDTA is effective against the inorganic components and sodium hypochlorite against the organic components present in the root canal. It was also observed that solution form was more effective than gel form.

In summary, 17% EDTA has proved successful in removing smear layer thus increasing the penetration of medicaments into the dentinal tubules and increasing the adaptability and penetration of filling materials into the

canal walls, thus favoring the achievement of a higher level of success of the endodontic treatment.

Future Research

Studies with larger sample size, studies with elaborate search strategies required for better result. Also In-vivo research is required to investigate the biocompatibility and clinical efficacy of 17% EDTA alone and in combinations. The results of this review could lead to redirect efforts towards new protocols for removing smear layer in infected root canals looking for synergisms between new or already known chelating agents.

REFERENCES

- Haapasalo M, Endal U, Zandi H, Coil JM: Eradication of endodontic infection by instrumentation and irrigation solutions. *Endod Topics*, 2005; 10: 77–102.
- Sen BH, Wesselink PR, Turkun M: The smear layer: a phenomenon in root canal therapy. *Int Endod J*, 1995; 28: 141–148.
- Torabinejad M, Handysides R, Khademi AA, Bakland LK: Clinical implications of the smear layer in endodontics: a review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 2002; 94: 658–666.
- Peters, O.A., Schonenberger, K., and Laib, A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *Int. Endod. J*, 2001; 34: 221–230.
- Yin, X., Cheung, G.S., Zhang, C., Masuda, Y.M., Kimura, Y., et al. Micro-computed tomographic comparison of nickel-titanium rotary versus traditional instruments in C-shaped root canal system. *J. Endod*, 2010; 36: 708–712.
- Zehnder, M. Rootcanalirrigants *J. Endod*, 2006; 32: 389–398.
- McComb D, Smith DC. A preliminary scanning electron microscopic study of root canals after endodontic procedures. *J Endod*, 1975; 1: 238- 42.
- Johal S, Baumgartner JC, Marshall G. Comparison of the antimicrobial efficacy of 1,3% NaOCl/BioPure MTAD to 5,25% NaOCl/15% EDTA for root canal irrigation. *J Endod*, 2007; 33: 48-51.
- Hülsmann M, Heckendorff M, Lennon A. Chelating agents in root canal treatment: Mode of action and indications for their use. *Int Endod J*, 2003; 36: 810-30.
- Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: A review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 2002; 94: 658-66.
- 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. *J Endod*, 2007; 33: 96-105.
- Sousa SM, Bramante CM, Taga EM. Biocompatibility of EDTA, EGTA and citric acid. *Braz Dent J*, 2005; 16: 3-8.
- Carvalho RM, Tay FR, Sano H, Yoshiyama M, Pashley DH. Long-term mechanical properties of EDTA-demineralized dentin matrix. *J Adhes Dent*, 2000; 2: 193-199.
- Fuentes V, Ceballos L, Osorio R, Toledano M, Carvalho RM, Pashley DH. Tensile strength and microhardness of treated human dentin. *Dent Mater*, 2004; 20: 522-529.
- Cederlund A, Jonsson B, Blomlof J. Do intact collagen fibers increase dentin bond strength? *Swed Dent J*, 2002; 26: 159-166.
- Sauro S, Mannocci F, Toledano M, Osorio R, Pashley DH, Watson TF. EDTA or H3PO4/ NaOCl dentine treatments may increase hybrid layers' resistance to degradation: A microtensile bond strength and confocal-micropermeability study. *J Dent*, 2009; 37: 279-288.
- Menezes AC, Zanet CG, Valera MC. Smear layer removal capacity of disinfectant solutions used with and without EDTA for the irrigation of canals: a SEM study. *Pesqui Odontol Bras*, 2003; 17(4): 349-55.
- Wadhvani KK, Tikku AP, Chandra A, Shakya VK. A comparative evaluation of smear layer removal using two rotary instrument systems with ethylenediaminetetraacetic acid in different states: a SEM study. *Indian J Dent Res*, 2011; 22(1): 10-5.
- Dadresanfar B, Khalilak Z, Delvarani A, Mehrvarzfar P, Vatanpour M, Pourasadollah M. Effect of ultrasonication with EDTA or MTAD on smear layer, debris and erosion scores. *J Oral Sci*, 2011; 53(1): 31-6.
- Prado M, Gusman H, Gomes BP, Simão RA. Scanning electron microscopic investigation of the effectiveness of phosphoric acid in smear layer removal when compared with EDTA and citric acid. *J Endod*, 2011; 37(2): 255-8.
- Zhu X, Yin X, Chang JW, Wang Y, Cheung GS, Zhang C. Comparison of the antibacterial effect and smear layer removal using photon-initiated photoacoustic streaming aided irrigation versus a conventional irrigation in single-rooted canals: an in vitro study. *Photomed Laser Surg*, 2013; 31(8): 371-7.
- Protogerou E, Arvaniti I, Vlachos I, Khabbaz MG. Effectiveness of a canal brush on removing smear layer: a scanning electron microscopic study. *Braz Dent J*, 2013; 24(6): 580-4.
- Kirchhoff AL, Viapiana R, Miranda CE, Sousa Neto MD, Cruz Filho AM. Comparison of the apple vinegar with other chelating solutions on smear layer and calcium ions removal from the root canal. *Indian J Dent Res*, 2014; 25(3): 370-4.
- Guo X, Miao H, Li L, Zhang S, Zhou D, Lu Y, Wu L. Efficacy of four different irrigation techniques combined with 60 °C 3% sodium hypochlorite and 17% EDTA in smear layer removal. *BMC Oral Health*, 2014; 14: 114. DOI: 10.1186/1472-6831-14-114.