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Evaluation of time exposure of different irrigation agents on radicular dentin erosion

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Abstract

Aim: The amount of root dentin erosion caused by Ethylene diamine tetraacetic acid (EDTA), Glycolic acid (GA), and Etidronic acid (HEDP) solutions applied with sonic activation (SA) for 1 and 3 minutes during the final irrigation was evaluated in this in vitro study.

Methods: Using 5 ml of 2.5% NaOCl irrigation solution in each sample, 70 mandibular premolars were enlarged with the Reciproc R25 rotary instrument system. The samples were randomly divided according to the final irrigation protocol into 6 experimental groups (n:10) and 1 control group (n:10): Group 1 (17% EDTA - 1 min SA), Group 2 (17% EDTA - 3 min SA), Group 3 (10% GA - 1 min SA), Group 4 (10% GA - 3 min SA), Group 5 (18% HEDP - 1 min SA), Group 1 (18% HEDP - 3 min SA) and Group 7 (Negative control group-distilled water, 1 min SA). The teeth were divided into two parts longitudinally after the final irrigation protocol. A low vacuum scanning electron microscope (SEM) was used to image the samples' coronal, middle, and apical root areas at x2000 magnification. Samples were evaluated using a triple-scoring system.

Results: Data were analyzed by Shapiro Wilk, Kruskal Wallis H, Mann-Whitney U, and Dunn's tests. There was no statistically significant difference between EDTA, GA, and HEDP in both periods ($p > 0.05$).

Conclusion: We saw similar amounts of erosion in dentin in 1 and 3 minutes of chelation applications for all chelators. Considering the smear removal efficiency of chelators, there is no harm in increasing the time in terms of erosion. There is a need for studies on the clinical applicability of chelation with a different duration time.

Keywords: Glycolic acid, EDTA, Etidronic acid, dentin erosion, chelating agents, sonic activation

Introduction

Endodontic treatment's success depends on removing vital and necrotic residues, microorganisms, and toxins from the pulp tissues of the root canal system [1]. However, the fact that the root canal system is quite complex and variable makes cleaning and disinfecting difficult. Since it is impossible to reach the isthmus and accessory canals with instrumentation, root canal disinfection with irrigation agents is important in endodontics [2].

Irrigation solutions commonly used today have only some of the ideal properties [3]. Dual irrigation combinations are therefore recommended in endodontic treatment. To that end, the most recommended EDTA-Sodium Hypochlorite (NaOCl) combination [4]. The application of EDTA at a concentration of 17% has negative features such as causing dentin erosion in the increased time, low-level antimicrobial activity, and limiting antimicrobial activity by reacting with NaOCl [3]. Consequently, the search for a chelation agent that provides an effective cleaning in the canal and does not cause dentin erosion has emerged.

Glycolic acid (GA), an organic compound belonging to the Hydroxy Acetic acid group, is frequently used in the pharmaceutical industry. It is a colorless, odorless, and hygroscopic crystalline solid with high solubility in water [5]. GA is preferred in mineral-containing dental structures because of its low pKa (ionization constant), low molecular weight, and organic structure [6]. It has recently been proposed that phosphoric acid be replaced as a surface abrasive for enamel and dentin [6]. Besides, GA is a readily biodegradable material [7].

Etidronic acid, also known as 1-hydroxyethane 1,1-diphosphonic acid (HEDP) or etidronate, is a bisphosphonate used in water treatment, cosmetic, detergent, and pharmaceutical treatment. Etidronate does not reduce its effectiveness when used with NaOCl. Since HEDP is a weak chelator, it is stated that it causes less dentin damage than EDTA [8]. HEDP is a biocompatible chelator that can be used with sodium hypochlorite without the short-term loss of the desired properties of either compound. The mixture of NaOCl and HEDP has the ability to reduce smear layer formation and reducing the accumulation of hard tissue debris during root canal instrumentation to an extent similar to the traditional use of NaOCl followed by EDTA [9].

Along with the chemical properties of the solution, the effectiveness of irrigation solutions also depends on the amount, temperature, contact time with the dentin surface, and the technique used to deliver the solution to the root canal system [10]. To that end, various activation methods are used to increase the effectiveness of irrigation agents used in endodontic treatment. Sonic and ultrasonic activation systems are one of them. The reason for their development was the difficulty of accessing the irregularities in the root canals with traditional irrigation methods and the thought that debris residues may remain in these areas [11.

Erosion is chemical wear due to external or internal acids or chelators acting on tooth surfaces [12]. Removing the smear layer will reduce microleakage and provide a good bond with the sealer. However, while doing this, erosion caused by chelators may destroy dentinal tubules [12]. Therefore, this research design was based on the effect of increased chelator application time on erosion. When the literature is reviewed, no study has been found comparing the effects of these three chelation agents on root dentin erosion over time.

This study compares the erosive activities of EDTA, GA, and HEDP solutions on the dentin surface. The null hypothesis of this study is that there will be no significant difference between the chelation agents used in the study in terms of their effects on dentin erosion. The alternative hypothesis of this study was that 3 minutes of chelation would cause more dentin erosion than 1 minute of chelation.

Materials and Methods

Selection of teeth and preparation of samples

This in vitro study design has been formatted and written following the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021' guidelines [13]. This study was approved by Dicle University, Faculty of Dentistry, Ethics Committee (Decision number 2021/41).

The sample size was calculated using the G*Power program (Version 3.1.9.7, HHU, Düsseldorf, Germany). According to 80% confidence (1-α), and 80% test power (1-β), there should be at least nine teeth in each group according to the previous studys' erosion mean values [14]. Seventy single-rooted non-carious human mandibular premolar teeth were used in this study. Inclusion criterias were single root, single canal, and single apical foramen extracted for orthodontic or periodontal reasons. Exclusion criterias were evidence of root canal calcification, apical resorption, immature root apices, root perforation, or fracture.

To standardize the root length, the crowns of the teeth were cut 15 mm from the enamel-cementum border to the root tip under water cooling with the help of an aerator. The working length of the remaining roots was determined to be 0.5 mm shorter after the appearance of the tip of file #15 K (VDW, Munich, Germany) from the apical foramen. The root tip of each sample was sealed with wax to simulate its anatomical position in the mouth and fixed in the polyvinyl siloxane impression material (Zetaplus, Zhermack Spa, Badia Polesine, Rovigo, Italy) in cylindrical plastic containers with a diameter of 3 cm for ease of preparation and irrigation. Root canals were enlarged using a Reciproc R25 (VDW, Munich, Germany) file. During the preparation of the canals, irrigation was performed with an irrigation needle (30 gauge) with apical occlusion and perforation on one side using 5 ml of 2.5% NaOCl solution. During the preparation process, each time the file was taken out of the canal, it was cleaned with a damp sponge, and the debris residues were removed. Finally, the root canals were washed with 2 ml of distilled water. Samples were numbered and randomly distributed www.random.org).

Then samples were divided into seven groups EDTA - 1 min, EDTA - 3 min, GA - 1 min, GA - 3 min, HEDP - 1 min, HEDP - 3 min, and a negative control group (n=10).

Group 1 (17% EDTA – 1 min SA):

Samples were applied with 2 mL of 17% EDTA (Saver, Prime Dental Products PVT Corp, Maharashtra, India). Activation was performed for 1 min with the VDW EDDY sonic device (VDW Gmbh, Munich, Germany).

Group 2 (17% EDTA – 3 min SA):

Samples were applied with 2 mL of 17% EDTA. Activation was performed for 3 min with the VDW EDDY sonic device.

Group 3 (10% GA – 1 min SA):

2 mL of 10% GA (Doğal Medicine Co, İzmir, Turkey) was applied. Activation was performed for 1 min with the VDW EDDY sonic device.

Group 4 (10% GA – 3 min SA):

Samples were applied with 2 mL of 10% GA. Activation was performed for 3 min with the VDW EDDY sonic device.

Group 5 (18% HEDP – 1 min SA):

2 mL of 18% HEDP (Akbel Chemical Co, Bursa, Turkey) was applied. Activation was performed for 1 min with the VDW EDDY sonic device.

Group 6 (18% HEDP – 3 min SA):

Samples were applied with 2 mL of 18% HEDP. Activation was performed for 3 min with the VDW EDDY sonic device.

Group 7 (Negative control group – 1 min SA):

Samples in the negative control group were irrigated with distilled water (DW) at the final irrigation. Activation was performed for 1 min with the VDW EDDY sonic device.

SEM evaluation (Erosion)

After the canal irrigation with chelators, irrigation was performed using 10 ml of 2.5% NaOCl for all groups. Then, the canals were washed with 2 mL of distilled water and dried with paper cones (R25 RECIPROC Paper Points, VDW, Munich, Germany). Root canal preparation and irrigation activation were performed by a single operator (Ö.F.O). Grooves parallel to the long axis of the buccal and lingual surfaces of the samples were opened after the preparation and irrigation protocol was completed. These grooves were created underwater cooling with the help of a thin flame-tipped milling cutter attached to the 300,000 rev/min aerator with water cooling in such a way that it would not contact the channel integrity. Afterward, only one-half of each root was used for SEM (Scanning electron microscope) imaging (Quanta FEG 250; FEI, Hillsboro, Oregon, USA) by dividing the samples longitudinally into two parts. With the SEM device, images of the root canals of the teeth were taken from the coronal, middle, and apical triple regions at x2000 magnification and under 20,000 kV. SEM images of the samples according to the regions are given in Figure 1.

Images were taken from the central parts of each region. Erosion grades were made according to the triple scoring system used by Torabinajed et al [10].

- **Score 1:** No erosion. All tubules are exhibited normal appearance and size.
- **Score 2:** Moderate erosion. Erosion of peritubular dentin was observed.
- **Score 3:** Severe erosion. The intertubular dentin was destroyed, and tubules were connected.

Two blind independent operators evaluated the SEM images and scored separately (S.K, M.Y.Ö).

Statistical analysis

Data were analyzed with IBM SPSS V23 (IBM, Armonk, NY, USA). The suitability of the data to the normal distribution was examined using the Shapiro-Wilk test. Dentin erosion score was compared according to regions and groups using the Kruskal Wallis test, and multiple comparisons were made with the Dunn's test.

Dentin erosion score was compared according to subgroups using the Mann-Whitney U test. Analysis results are shown as mean ± sd and median (minimum-maximum). In the interpretation of the results, 0.05 was used as the significance level, and if $p < 0.05$, it was stated that there was a significant difference. The intraobserver agreement was calculated using Cohen's kappa statistics.

Results

The kappa test results indicated no statistically significant differences between inter-examiner values for scoring the erosion in each group (kappa value = 0.879).

There was no statistically significant difference between the distributions of the dentin erosion scores in the groups' coronal, middle, and apical regions in both 1 min and 3 min periods ($p > 0.05$). Besides, there was no significant difference in the evaluations of the groups within themselves depending on the duration ($p > 0.05$). Comparison of dentin erosion scores by groups within each subgroup and region is shown in Table 1.

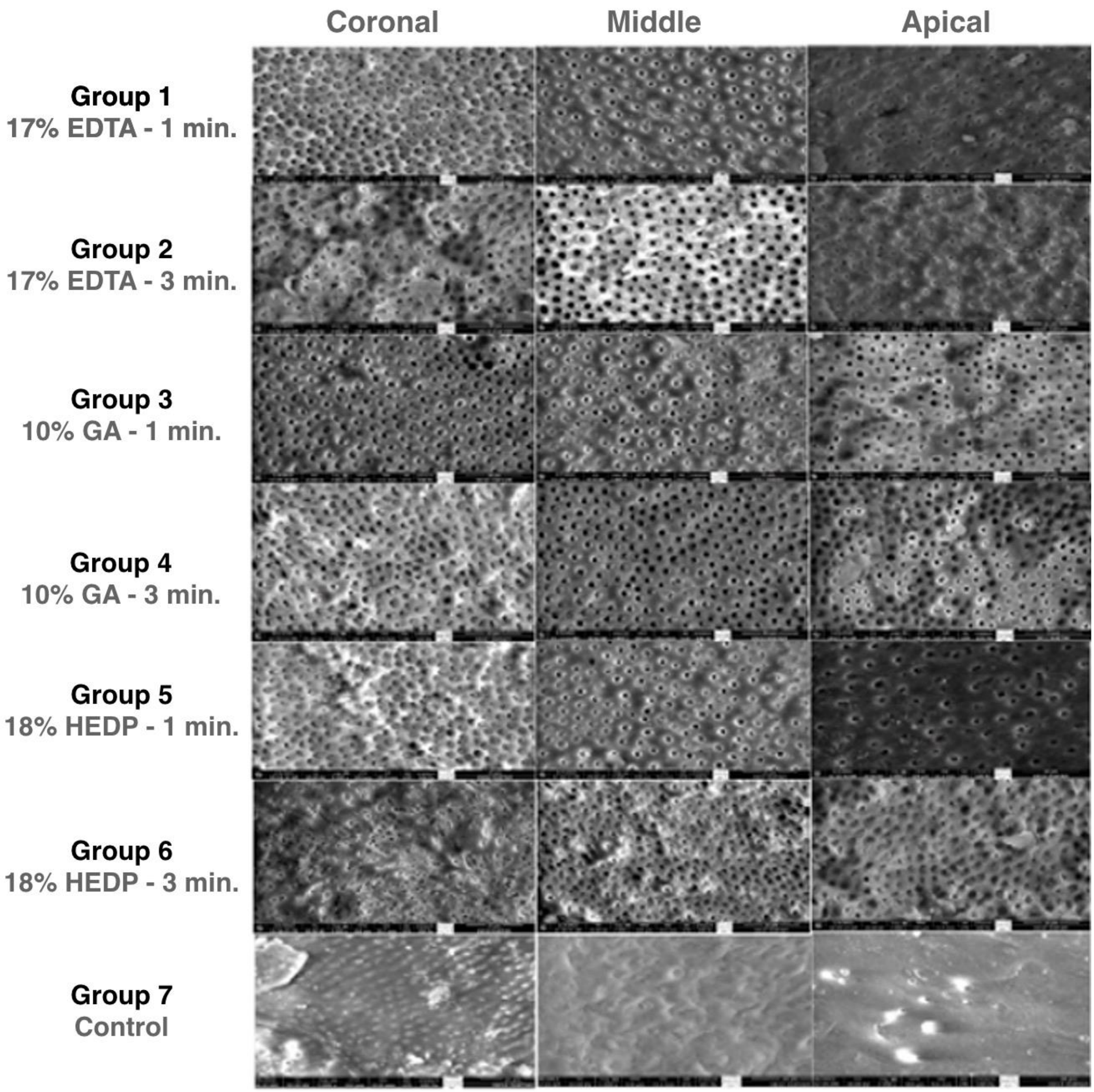

Figure 1. SEM images of samples by region (x2000 magnification). In the comparison of the groups, score 2 and score 3 were observed mostly in the coronal and middle regions in terms of erosion.

Table 1. Comparison of dentin erosion score by groups within each subgroup and region. Data were analyzed by Shapiro Wilk's, Kruskal Wallis, Mann-Whitney U, and Dunn's tests

Time	Section	Groups EDTA Mean ± SD Median (Min-Max)	HEDP Mean ± SD Median (Min-Max)	GA Mean ± SD Median (Min-Max)	p
1 min	Coronal	2,00 ± 0,67	1,80 ± 0,63	1,60 ± 0,52	0,375
		2,00 (1,00 - 3,00)	2,00 (1,00 - 3,00)	2,00 (1,00 - 2,00)	
	Middle	1,70 ± 0,82	1,60 ± 0,52	1,70 ± 0,67	0,972
		1,50 (1,00 - 3,00)	2,00 (1,00 - 2,00)	2,00 (1,00 - 3,00)	
	Apical	1,80 ± 0,63	1,70 ± 0,48	1,80 ± 0,63	0,936
		2,00 (1,00 - 3,00)	2,00 (1,00 - 2,00)	2,00 (1,00 - 3,00)	
3 min	Coronal	2,10 ± 0,57	1,80 ± 0,92	1,60 ± 0,52	0,261
		2,00 (1,00 - 3,00)	1,50 (1,00 - 3,00)	2,00 (1,00 - 2,00)	
	Middle	2,00 ± 0,67	1,50 ± 0,53	1,50 ± 0,53	0,139
		2,00 (1,00 - 3,00)	1,50 (1,00 - 2,00)	1,50 (1,00 - 2,00)	
	Apical	1,50 ± 0,53	1,60 ± 0,52	1,70 ± 0,48	0,668
		1,50 (1,00 - 2,00)	2,00 (1,00 - 2,00)	2,00 (1,00 - 2,00)	

* SD: standard deviation

Discussion

In this study, the effects of EDTA, GA, and HEDP solutions on dentin erosion depending on the time were compared, and the absence of statistical difference enabled the null hypothesis to be confirmed.

Chelators demineralize the root canal walls, leaving them almost devoid of the soft and permeable mineralized surface [15]. Prolonged contact of chelating agents with dentin not only removes dentin residues but also causes erosion of dentin surfaces through the process of demineralization and excessive opening of tubules. In this way, the adhesion of the filling material to the canal walls becomes difficult, and the tightness is reduced. As a result of poor bonding, increased bacterial permeability may fail root canal treatment [15].

The tissue-dissolving property of EDTA, the popular chelating agent, is not only selective for dentin residues, and its demineralizing effect may result in root canal walls lacking a soft and permeable mineralized surface [16]. For this reason, many studies in the literature investigate the effects of the type, volume, concentration, pH, and application time of the irrigation agent on the root canal dentin and dentin tubules [16-18]. This study aimed to compare the erosive effect of three different chelation agents on dentin tissue in 1- and 3- min periods. In our study, no difference was found in erosion according to the application time in any of the chelators. Thus, the alternative hypothesis was rejected.

In one study, the order of exposure of root canal wall dentin to NaOCl and EDTA has been shown to significantly affect the level of dentin erosion. The authors found that erosion was significantly increased when washing with NaOCl after chelators. On the other hand, it is known that when EDTA is used with NaOCl, the hypochlorite anion in the solution decreases, and the antibacterial activity and effect of NaOCl in dissolving necrotic pulp are reduced [18, 19]. Therefore, our study used NaOCl for all groups and application times after chelator application procedures. This situation may have increased the erosion relatively in all groups.

In one study, the authors examined erosion of radicular dentin after NaOCl at two different concentrations (5.25% and 1.3%) followed by 17% EDTA. The authors concluded that the destructive effect of NaOCl on mineralized dentin is irreversible, and erosion is present regardless of whether EDTA is used as the final irrigation agent [20].

Şen et al. investigated the smear removal and erosion capacities of 15%, 10%, 5%, and 1% EDTA and showed that 1% EDTA removed the smear sufficiently and caused less erosion. There was no significant difference between erosion levels in the apical, middle, and coronal regions for all percentages of EDTA [21]. In another study, when citric acid and boric acid were used, they did not find a significant difference in erosion between the apical, middle, and coronal regions [22]. These results were compatible with our study. We observed similar erosion levels in all tooth regions.

GA has been a popular chelation agent in recent years. Studies have been done on removing smears and calcium hydroxide [23-26]. Souza et al. compared 10%, 17%, and 25% GA in cytotoxicity and microhardness. They stated that 10% GA removed the smear layer at the optimum level and cytotoxicity was low [27]. Therefore, 10% GA was preferred in our study. Previous studies reported that using GA at 5%, 10%, and 17% concentrations to remove the smear layer shows similar results with EDTA in the coronal and middle third of the root canals [26]. Our study found that EDTA and GA had a similar level of erosion in the same tooth regions as in the previous study. Türk et al. found that the most effective solution for removing the smear layer was 2.5% citric acid; this solution was the most erosive solution [22]. Thus, considering the relationship between erosion and smear layer removal, the erosive effect of the solutions in our study may be compatible with the previous smear removal literature.

In the literature, the erosional efficiency of HEDP differs in studies. Ulusoy et al. showed that peracetic acid and EDTA alone and in combination with NaOCl did not cause erosion, while HEDP alone and NaOCl caused dentin erosion [28]. They attributed this result to the wettability and penetration ability of HEDP. In addition, the authors suggested that 9% HEDP applied for 2 minutes can be applied for 1 minute to reduce the amount of erosion [28]. In a smear removal and erosion study, the combination of HEDP and NaOCl (DualRinse) and NaOCl application after EDTA were compared, and they found no significant difference between the groups [29]. In the current study, we have seen that the erosion caused by HEDP was similar to other chelators.

Qian et al. used different chelators on dentin erosion in different sequences. They stated that due to the prevalence of sclerotic dentin in the apical third of the root, it would not be possible to assess erosion accurately in this region [17]. In our study, we also evaluated erosion in the apical third. In our study, tooth ages are not known because the teeth were selected from a tooth pool. For this reason, the presence of sclerotic dentin may have caused an incorrect evaluation of the images.

In dentin erosion studies, dentin sections were examined under 1000x and 4000x magnifications [17, 29-31]. In our study, we preferred 2000 magnification, where we could simultaneously see more dentinal tubules and peritubular dentin.

Activation of irrigation can greatly facilitate the removal of the smear layer from the apical portion of the root canal. To achieve this goal, some form of the root canal walls with chelators may be required. However, this may also affect the incidence of moderate or severe abrasion/erosion of the root canal wall [32]. In a study evaluating the effects of GA with different pH values (with pH 1.2 and 5) and EDTA on the chemical and mechanical properties of dentin, EDTA caused significantly more erosion in the coronal than apical GA, with similar erosions in all parts of the root [18]. In our study, GA showed similar erosion for each root level. This may be because the percentage is different, and the chelator is activated with EDDY.

Contrary to the knowledge that increasing application time increases erosion, dentin erosion after 1 and 3 minutes of application was similar in our study [1]. Activation of chelating agents may have affected the erosion capacity.

This study showed that chelators cause erosion in application time exceeding 1 minute. There is a need for more studies in the literature that change the application time. It has also been reported that using SEM to examine the smear layer is not reliable and reproducible. The use of different magnifications in the studies makes the assessments inconsistent [33, 34]. Considering the in vitro conditions in this study, the unknown age of the tooth and the fact that the body temperature was not simulated during the canal preparation are the study's limitations.

Conclusion

According to our study results within all these data, although all three solutions give similar results in terms of the erosion areas they create in dentin, it is an advantage that GA is not synthetic like EDTA and can be dissolved biologically without toxic effects on tissues. HEDP does not react with NaOCl, an organic tissue solvent, and the advantage of using it together shows that they are solutions that can be an alternative to EDTA.

Moreover, increasing the time to remove the smear may not increase erosion. More studies are needed on the application time of chelators to reduce erosion.

Disclosures

Ethics Committee Approval: This study was approved by the Ethics committee of Dicle University, Faculty of Dentistry (Approval Number: 2021/41).

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – Ö.F.O.; Design – Ö.F.O., S.K.; Supervision – S.K.; Materials – Ö.F.O., S.K.; Data collection &/or processing – Ö.F.O., S.K.; Analysis and/or interpretation – M.Y.Ö.; Literature search – Ö.F.O., Ö.A.; Writing – Ö.F.O.; Critical review – Ö.A.

Conflict of Interest: There is no any conflict of interest.

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References

1. Violich D, Chandler N. The smear layer in endodontics-a review. Int Endod J 2010;43:2-15. https://doi.org/10.1111/j.1365-2591.2009.01627.x
2. Zehnder M. Root canal irrigants. J Endod 2006;32:389-98. https://doi.org/10.1016/j.joen.2005.09.014

3. Niu W, Yoshioka T, Kobayashi C, Suda H. A scanning electron microscopic study of dentinal erosion by final irrigation with EDTA and NaOCl solutions. Int Endod J 2002;35:934-39. https://doi.org/10.1046/j.1365-2591.2002.00594.x
4. Haapasalo M, Shen Y, Qian W, Gao Y. Irrigation in endodontics. Dent Clin 2010;54:291-312. https://doi.org/10.1016/j.cden.2009.12.001
5. Thibault PK, Wlodarczyk J, Wenck A. A double-blind randomized clinical trial on the effectiveness of a daily glycolic acid 5% formulation in the treatment of photoaging. Derma surg 1998;24:573-8. https://doi.org/10.1111/j.1524-4725.1998.tb04209.x
6. Cecchin D, Farina AP, Vidal CM, Bedran-Russo AK. A novel enamel and dentin etching protocol using α-hydroxy glycolic acid: Surface property, etching pattern, and bond strength studies. Oper Dent 2018;43:101-10. https://doi.org/10.2341/16-136-L
7. Hua X, Cao R, Zhou X, Xu Y. One-step continuous/semi-continuous whole-cell catalysis production of glycolic acid by a combining bioprocess with in-situ cell recycling and electrodialysis. Biores techno 2019;273:515-20. https://doi.org/10.1016/j.biortech.2018.11.061
8. Tartari T. Vila Nova de Almeida B, Carrera Silva Júnior JO, Facíola Pessoa O. A new weak chelator in endodontics: effects of different irrigation regimens with etidronate on root dentin microhardness. Int J Dent 2013. https://doi.org/10.1155/2013/743018
9. Öztekin F, Elmalı E. The effect of irrigation solutions and sterilization process on the surface properties of ProTaper Next and TruNatomy rotary files: An atomic force microscopy study. Int Dent Res 2022;12(2):39-46. https://doi.org/10.5577/intdentres.2022.vol12.no2.1
10. Torabinejad M, Cho Y, Khademi AA, Bakland LK, Shabahang S. The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. J Endod 2003;29:233-9. https://doi.org/10.1097/00004770-200304000-00001
11. Gu L-s, Kim JR, Ling J, Choi KK, Pashley DH, Tay FR. Review of contemporary irrigant agitation techniques and devices. J Endod 2009;35:791-804. https://doi.org/10.1016/j.joen.2009.03.010
12. Ganss C. Definition of erosion and links to tooth wear. In: Dental erosion. Karg Publish; 2006. p. 9-16. https://doi.org/10.1159/000093344
13. Nagendrababu V, Murray P, Ordinola-Zapata R, Peters O, Rôças I, Siqueira Jr J, et al. A protocol for developing reporting guidelines for laboratory studies in Endodontology. Int Endod J 2019;52:1090-5. https://doi.org/10.1111/iej.13125
14. Cehreli ZC, Uyanik MO, Nagas E, Tuncel B, Er N, Comert FD. A comparison of residual smear layer and erosion following different endodontic irrigation protocols tested under clinical and laboratory conditions. Acta Odontol Scandinav 2013;71,1261-6. https://doi.org/10.3109/00016357.2012.757647
15. Fernández ML, Pérez GG, Villagómez MO, Villagómez GO, Báez TDM, Lara GG. In vitro study of erosion caused by EDTA on root canal dentin. Rev Odont Mexi 2012;16:8-13.
16. Kaya S, Yiğit-Özer S, Adigüzel Ö. Evaluation of radicular dentin erosion and smear layer removal capacity of Self-Adjusting File using different concentrations of sodium hypochlorite as an initial irrigant. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:524-30. https://doi.org/10.1016/j.tripleo.2011.02.039
17. Qian W, Shen Y, Haapasalo M. Quantitative analysis of the effect of irrigant solution sequences on dentin erosion. J Endod 2011;37:1437-41. https://doi.org/10.1016/j.joen.2011.06.005
18. Barcellos DPDC, Farina AP, Barcellos R, Souza MA, Borba M, Bedran-Russo AK, et al. Effect of a new irrigant solution containing glycolic acid on smear layer removal and chemical/mechanical properties of dentin. Scient Reports 2020;10:1-8. https://doi.org/10.1038/s41598-020-64450-1
19. Dalpino P, Francischone CE, Ishikiriama A, Franco EB. Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials. Am J Dent 2002;15:389-94.
20. Zhang K, Tay FR, Kim YK, Mitchell JK, Kim JR, Carrilho M, et al. The effect of initial irrigation with two different sodium hypochlorite concentrations on the erosion of instrumented radicular dentin. Dent Mater 2010;26:514-23. https://doi.org/10.1016/j.dental.2010.01.009
21. Şen BH, Ertürk Ö, Pişkin B. The effect of different concentrations of EDTA on instrumented root canal walls. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:622-7. https://doi.org/10.1016/j.tripleo.2009.04.042
22. Turk T, Kaval ME, Şen BH. Evaluation of the smear layer removal and erosive capacity of EDTA, boric acid, citric acid and desy clean solutions: an in vitro study. BMC Oral Health 2015;15:1-5. https://doi.org/10.1186/s12903-015-0090-y
23. Keskin C, Keleş A, Sarıyılmaz Ö. Efficacy of glycolic acid for the removal of calcium hydroxide from simulated internal Resorption cavities. Clin Oral Investig 2021;25:4407-13. https://doi.org/10.1007/s00784-020-03753-z
24. Dal Bello Y, Porsch HF, Farina AP, Souza MA, Silva EJNL, Bedran-Russo AK, et al. Glycolic acid as the final irrigant in endodontics: Mechanical and cytotoxic effects. Mater Sciens and Eng: C 2019;100:323-9. https://doi.org/10.1016/j.msec.2019.03.016
25. Dal Bello Y, Farina AP, Souza MA, Cecchin D. Glycolic acid: Characterization of a new final irrigant and effects on flexural strength and structural integrity of dentin. Mater Sciens and Eng: C 2020;106:110283. https://doi.org/10.1016/j.msec.2019.110283
26. de Andrade Marafiga F, Barbosa AFA, Silva EJNL, Souza MA, Farina AP, Cecchin D. Effect of glycolic acid and EDTA on dentin mechanical properties. Aust Endod J 2022;48:27-31. https://doi.org/10.1111/aej.12606
27. Souza MA, Bischoff KF, Rigo BD, Piuco L, Didoné AV, Bertol CD, et al. Cytotoxicity of different concentrations of glycolic acid and its effects on root dentin microhardness-An in vitro study. Aust Endod J 2021;47:423-8. https://doi.org/10.1111/aej.12494
28. Ulusoy Ö, Mantı A, Çelik B. Nanohardness reduction and root dentine erosion after final irrigation with ethylenediaminetetraacetic, etidronic and peracetic acids. Int Endod J 2020;53:1549-58. https://doi.org/10.1111/iej.13372
29. Kfir A, Goldenberg C, Metzger Z, Hülsmann M, Baxter S. Cleanliness and erosion of root canal walls after irrigation with a new HEDP-based solution vs. traditional sodium hypochlorite followed by EDTA. A scanning electron microscope study. Clin Oral Investig 2020;24:3699-706. https://doi.org/10.1007/s00784-020-03249-w
30. Paqué F, Luder H, Sener B, Zehnder M. Tubular sclerosis rather than the smear layer impedes dye penetration into the dentine of endodontically instrumented root canals. Int Endod J 2006;39:18-25. https://doi.org/10.1111/j.1365-2591.2005.01042.x
31. Wang Z, Maezono H, Shen Y, Haapasalo M. Evaluation of root canal dentin erosion after different irrigation methods using energy-dispersive X-ray spectroscopy. J Endod 2016;42:1834-9. https://doi.org/10.1016/j.joen.2016.07.024
32. Metzger Z, Solomonov M, Kfir A. The role of mechanical instrumentation in the cleaning of root canals. Endod Topics 2013;29:87-109. https://doi.org/10.1111/etp.12048
33. Gulabivala K, Patel B, Evans G, Ng YL. Effects of mechanical and chemical procedures on root canal surfaces. Endodo Topics 2005;10:103-22. https://doi.org/10.1111/j.1601-1546.2005.00133.x
34. Alamoudi RA. The smear layer in endodontic: To keep or remove-an updated overview. Saudi Endod J 2019;9:71-81.