

RESEARCH

Open Access



Histological evaluation of the debris removal efficiency of activation of sodium hypochlorite solution at different concentrations

Esin Özlek^{1*}, Eda Acikgoz², Nesibe Zeyneb Gökkaya¹, Ahmet Taşan¹ and Fikret Altındağ²

Abstract

Background This study aims to histologically evaluate the efficiency of debris removal through activation of 2.5% and 5.25% NaOCl using laser, ultrasonic, and intracanal heating methods.

Methods Sixty-four maxillary central incisor teeth were randomly divided into two groups according to the irrigation solution ($n=32$); 2.5% NaOCl and 5.25% NaOCl. Subsequently, the samples were further divided into four subgroups according to the final irrigation activation technique ($n=8$); SubgroupA: Er,Cs:YSGG laser, SubgroupB: Ultrasonic, Subgroup C: Intracanal heating, Subgroup D: no activation. Generalized Linear Models and Bonferroni tests were used for statistical analysis ($p < 0.05$).

Results The effect of NaOCl concentration was statistically significant ($p < 0.001$). Furthermore, the activation of NaOCl by laser exhibited a statistically significant difference compared to the ultrasonic and intracanal heating methods ($p < 0.001$).

Conclusion The efficiency of root canal cleaning increases with higher NaOCl concentration. Activation of NaOCl also significantly enhances its effectiveness.

Keywords Irrigation, Root canal preparation, Sodium hypochlorite, Irrigation activation technique, Er,Cs:YSGG laser

Introduction

Sodium hypochlorite (NaOCl) is widely used as an irrigation solution in endodontics due to its favorable physicochemical and antibacterial properties [1, 2]. Although NaOCl effectively dissolves necrotic tissue and smear layer, its extrusion beyond the root canal into the periapical tissues can lead to cytotoxic effects [3]. Systemic allergic reactions, hemolysis, ulceration, and necrosis may occur in living tissues. NaOCl concentrations

ranging from 0.5% to 5.25% are commonly used in endodontic treatments [4]. Previous studies have shown that the tissue-dissolving and antimicrobial activities of NaOCl vary depending on the concentration, volume, and contact time of the solution, with higher concentrations demonstrating greater effectiveness. However, it is known that increasing concentration of NaOCl also increases its cytotoxic effects [5]. Consequently, recent research in endodontics has focused on enhancing the efficacy of low concentrations of NaOCl [6]. Studies have reported that activation NaOCl improves both smear layer removal efficiency and antibacterial activity [7].

Passive ultrasonic irrigation (PUI) involves activating irrigation solutions used ultrasonic tips operating at frequencies of 25–40 kHz. This method increases the effective surface area of the solutions through

*Correspondence:

Esin Özlek
esin_ozlek@hotmail.com

¹ Department of Endodontics, Faculty of Dentistry, The University of Van Yuzuncu Yil, Van, Turkey

² Department of Histology and Embryology, Faculty of Medicine, The University of Van Yuzuncu Yil, Van, Turkey



© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

ultrasonic vibrations generated in the root canal, leading to more efficient cleaning [8, 9]. Verna et al. demonstrated that both passive ultrasonic irrigation and laser activated irrigation enhanced the success of endodontic treatments compared to traditional methods [10]. Recent studies have indicated that intracanal heating of NaOCI enhances the effectiveness of the solution [11, 12]. However, it remains unclear whether intracanal heating of low concentrations of NaOCI can achieve sufficient cleaning compared to high concentrations.

Therefore, the aim of this study is to histologically evaluate the efficiency of pulp residue and debris removal using both 2.5% and 5.25% NaOCI solutions, in combination with activation through laser, ultrasonic, and intracanal heating methods during the final irrigation step.

Materials methods

Ethical approval

Ethical approval for this study was obtained from the Institutional Review Board and the Ethics Committee of the University (2020/09–07).

Methodology

A total of 64 maxillary central incisor teeth with fully formed roots and closed apices were selected for his study. These teeth were extracted from individuals within the age group of 18–45 years for periodontal or

orthodontic reasons. Prior to inclusion, the teeth were examined under a stereomicroscope, and any teeth with cracks or fractures were excluded. Only teeth without root canal calcification or resorption and with a minimum root length of 15 mm were included. Soft and hard tissue accumulations on the teeth were removed using a curette, and the teeth were stored in distilled water at room temperature until use. The teeth were decoronated using a slow-speed diamond saw with liquid cooling to obtain standardized root lengths of 15 mm. A size 10 K-type file was inserted into the root canal, and the working length was determined to be 1 mm shorter than the length visible at the apical foramen. The samples were randomly divided into two groups according to the concentration of NaOCI to be used during root canal instrumentation ($n=32$); *G1*; 2.5% of NaOCI and *G2*; 5.25% of NaOCI (Fig. 1).

All samples were shaped up to X4 using the Pro-taper Next rotary file system(DenstplyMaillefer, Ballauges,Switzerland) and the X-Smart Plus (Dent-sply Maillefer, Ballauges, Switzerland) endodontic motor. Irrigation was conducted using 1 mL of either 2.5% or 5.25% NaOCI solution (Imicrly, Konya, Turkey) with a 31G side-vented needle during instrument change. Following instrumentation, the root canals were irrigated with 5 mL of 17% EDTA solution (Imident™ Med., Konya, Turkey) for 1 min to eliminate the smear layer. No

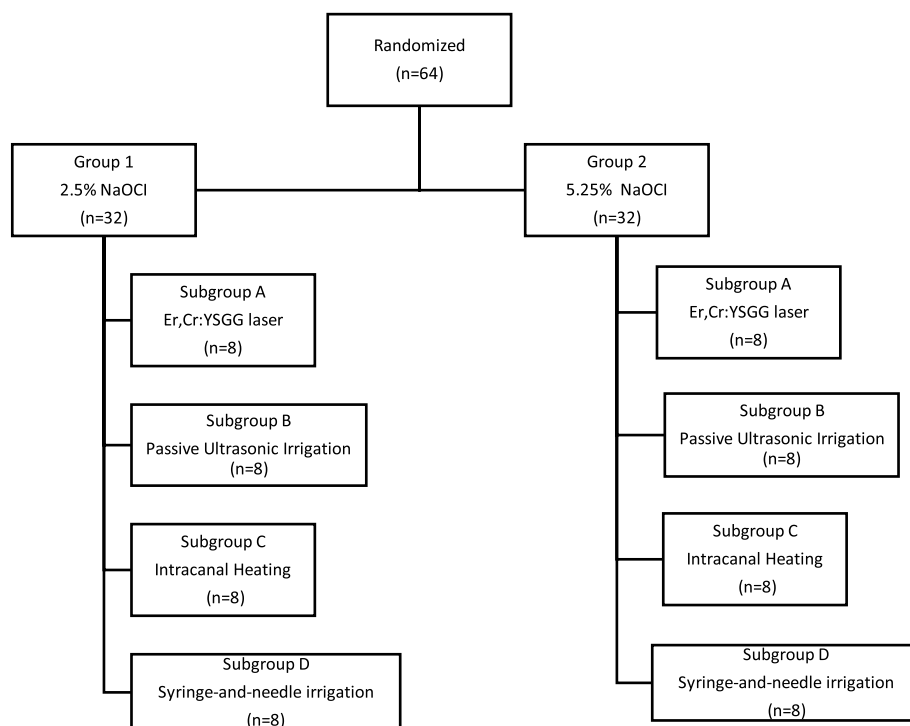


Fig. 1 Distribution of groups

additional solution was utilized between the NaOCl irrigation and the subsequent EDTA irrigation. Afterwards, the samples were randomly divided into four subgroups based on the method of final irrigation activation ($n=8$);

Subgroup A: Er,Cr:YSGG laser

The root canals were filled with NaOCl solution and activated using Er, Cr: YSGG laser (Waterlase MD, Biolase Technology Inc., San Clemente, CA, USA) with an RFT2 tip. The tip, with a diameter of 275 microns in diameter and a length of 21 mm, was placed 1 mm short of the working length. The laser parameters were set to an output power of 2W, pulse frequency of 20 Hz, and a combination of 10% air and 10% water. The laser activation was performed in a slow and helical motion from the apical area to the coronal area for 8 s. The tip was positioned away from the dentinal walls and activated for 8 s, followed by a 10-s of deactivation period. This activation procedure was repeated 3 times, using fresh NaOCl solution for each cycle.

Subgroup B: passive ultrasonic irrigation

NaOCl was activated using ultrasonic device (VDW, Munich, Germany). The device was set to a power setting of 30, and activation was performed using a 21 mm-IRR20 irrigation tip placed 1 mm behind the working length. The tip was positioned away from the dentinal walls and activated for 20 s. This activation procedure was repeated 3 times, using fresh NaOCl solution for each cycle.

Subgroup C: intracanal heating

NaOCl solution was placed in the root canals and intracanal heating was performed using System-B device (11). System-B device was set to 150 °C and an X-fine tip was placed in the root canal, positioned 3 mm shorter than the working length without touching the canal walls. The tip was positioned away from the dentinal walls and activated for 8 s, followed by a 10-s period of deactivation. This activation procedure was repeated 3 times, using fresh NaOCl solution for each cycle.

Subgroup D (control): Syringe-and-needle irrigation

The root canals were irrigated with NaOCl solution using a 31-gauge closed-end needle (Ayset, Adana, Turkey), placed 1 mm short of the working length. The needle was moved in short vertical strokes with an amplitude of 2–3 mm at an approximate rate of 100 strokes per minute.

A total of 5 mL of NaOCl solution was used for irrigation in all samples. The activation process was performed for a total of 1 min with 3 cycles of 20 s each (8 s active, 12 s waiting). The solution was refreshed for

each activation cycle. Following the activation process, all samples were washed with 5 mL of distilled water and dried with paper points.

Histological evaluation

After the completion of the endodontic procedures, all samples were fixed in 10% (v/v) neutral buffered formalin for 48 h and then washed under running tap water for 1 h. Decalcification of teeth was performed using a 5% nitric acid solution, with fresh solution being replaced every two days. The endpoint of decalcification was determined using a chemical method previously described in a study [13]. The tooth specimens were washed in running water for approximately 2 h and then dehydrated in ascending grades of ethanol, cleared in xylene, and embedded in paraffin. The samples were cut 5- μ m-thick by rotary microtome (Leitz, Wetzlar, Germany) and stained with hematoxylin–eosin (Fig. 2). The sections were then viewed under a light microscopy at magnifications of 20X and 40X. Debris, including dentin chips, pulp remnants, and other particles loosely attached to the root canal walls, were defined as debris (K1). The images were placed on a grid using Image-J (Image J; National Institutes of Health, Bethesda, MD), and the percentage of remaining debris was calculated by two independent examiners [2, 14].

Statistical analysis

The data were analyzed using IBM SPSS V23. The normal distribution of the data was assessed using the Kolmogorov-Smirnov test. The Generalized Linear Models method was used to evaluate the main effects of concentration and activation, as well as their interaction, on the amount of residual debris. Multiple comparisons were performed using the Bonferroni test. The results of the quantitative data analysis were presented as deviations. The level of significance was set at $p<0.05$.

Results

The main effect of concentration on the amount of residual debris was found to be statistically significant ($p<0.001$) (Table 1). The average residual debris for the 5.25% contraction was 0.255, while it was 0.312 for the 2.5% contraction. There was no statistically significant interaction between the method and concentration on the amount of residual debris ($p=0.713$). The main effect of the irrigation activation technique on the amount of residual debris was statistically significant ($p<0.001$) (Table 2). The mean residual debris for laser activation was 0.143, for passive ultrasonic activation was 0.229, for intracanal heating was 0.320, and for the unactivated control group was 0.443. The control

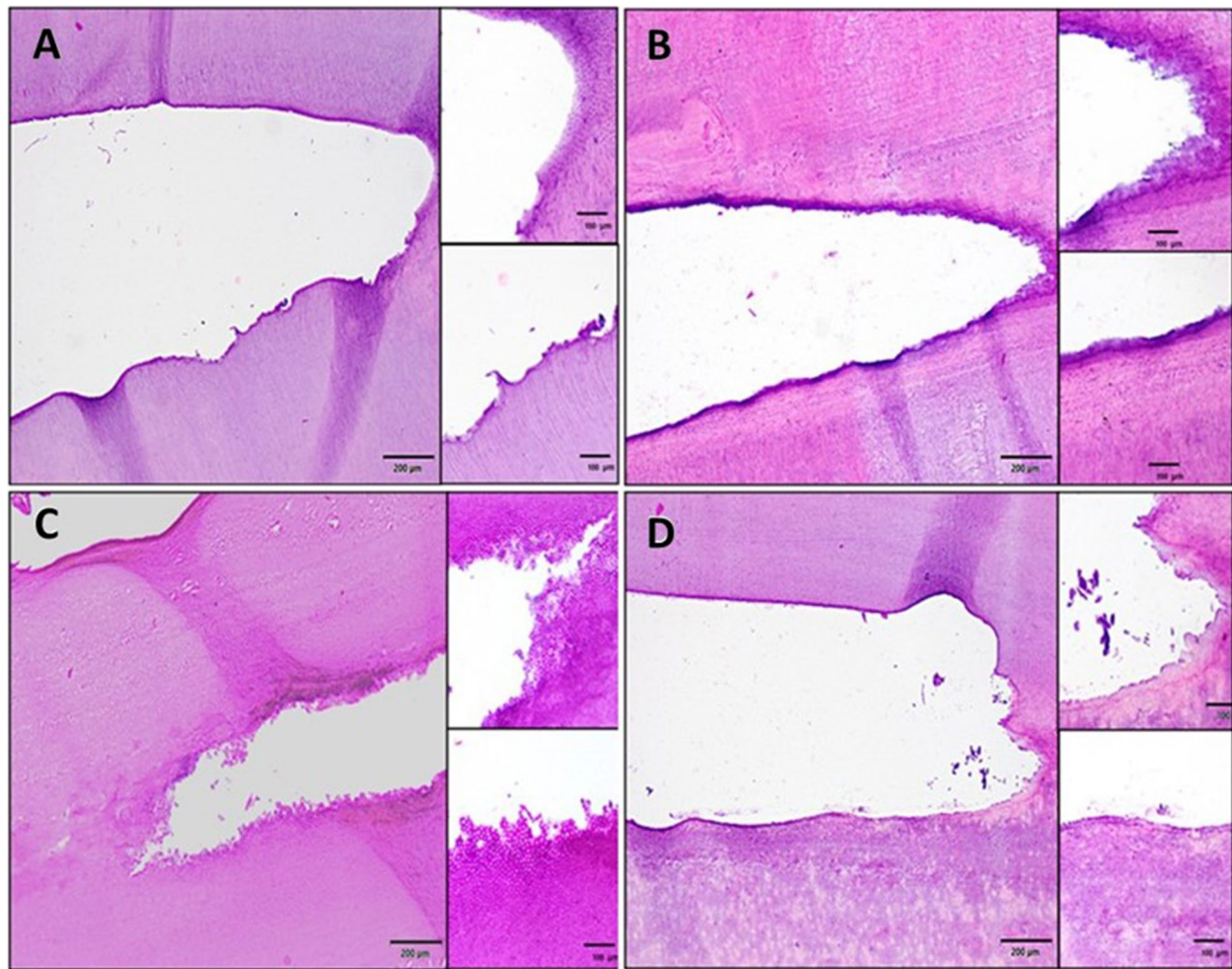


Fig. 2 Representative histological picture from root canals section; (A) Er,Cs:YSGG laser, (B) PUI, (C) Intracanal heating, (D) no activation

Table 1 Descriptive statistics

Activation Technique					
Concentration	Er,Cs:YSGG laser	PUI	Intracanal heating	Control	Mean
%5.25	0.100 ± 0.072	0.206 ± 0.156	0.288 ± 0.162	0.425 ± 0.249	0.255 ± 0.208
%2.5	0.186 ± 0.125	0.251 ± 0.140	0.351 ± 0.189	0.461 ± 0.223	0.312 ± 0.201
Total	0.143 ± 0.110 ^a	0.229 ± 0.149 ^b	0.320 ± 0.178 ^c	0.443 ± 0.236 ^d	0.284 ± 0.206

^{a-d}There is no difference between methods with the same letter

Table 2 Comparison of residual debris by activation technique and concentration

	Test statistic ^a	Sd	p
Activation technique	185.388	3	<0.001
Concentration	12.421	1	<0.001
Activation technique ^a	1.369	3	0.713
Concentration			

^aWald Chi-square test statistic

group had the highest mean amount of residual debris, while the laser group had the lowest mean amount of remaining debris.

Multiple comparisons revealed statistically significant differences in the mean amount of debris between the laser and passive ultrasonic activation, and between the laser and intracanal heating method, and between passive ultrasonic and intracanal heating method ($p < 0.001$).

Discussion

This study investigated the effects of different concentrations of NaOCl solution and various final irrigation techniques on the remaining pulp and debris in the root canal. The results showed that the 5.25% of NaOCl solution provided significantly better cleaning in the root canal compared to the 2.5% of NaOCl solution. Furthermore, when NaOCl solution was activated during the final irrigation, laser activation demonstrated a statistically significant difference compared to passive ultrasonic activation and intracanal heating method. Activation of the 2.5% of NaOCl solution using laser, passive ultrasonic, and intracanal heating method did not yield as much cleaning efficiency as the 5.25% of NaOCl solution.

Studies suggest that the toxicity of NaOCl increases with its concentration and that it should be used at the lowest effective concentration [5, 15]. Numerous studies in the literature have evaluated the effects of different NaOCl concentrations on antimicrobial activity, tissue dissolution, debris removal, and postoperative pain [15, 16]. However, despite these studies, there is still no consensus on the recommended optimal concentration of NaOCl. In a study by Siqueira et al. [17], which evaluated the antimicrobial effect of 1%, 2.5%, and 5.25% NaOCl, it was reported that all concentrations were effective, and the effect increased with higher concentrations. Ayhan et al. [18] compared the antimicrobial activity of 0.5% and 5.25% NaOCl on different microorganisms and found that the 0.5% concentration had a significantly lower effect. Baumgartner and Cuenin [19] reported that NaOCl concentrations of 0.5%, 1%, 2.5%, and 5.25% were capable of completely removing predentin and pulp tissue remnants from the unformed canal wall. In contrast, Goldsmith et al. [20] stated that diluting NaOCl up to 2.2% did not significantly reduce its tissue dissolving effect, but the effect of a 0.5% of NaOCl insufficient. More recently, Virdee et al. [6] reported that the penetration of the solution increased with higher NaOCl concentration and contact time. In the literature review, no study was found where the root canal cleaning efficiency of different NaOCl concentrations was evaluated histologically. Therefore, in this study, the debris removal efficiency of both 2.5% and 5.25% NaOCl solutions and different final irrigation techniques were evaluated. The results showed that the 5.25% NaOCl solution significantly improved root canal cleaning compared to the 2.5% NaOCl solution.

When reviewing the existing literature, a consensus emerges that as the concentration of the NaOCl solution increases, its effectiveness also increases. Consequently, 5.25% NaOCl solution is commonly preferred in clinical practice. Additionally, in recent years, irrigation activation methods have been recommended to

enhance solution effectiveness. This raises the question, “Is it possible to achieve the effects of high concentrations of NaOCl by activating low concentrations of NaOCl solution? Does this reduce toxicity?” In this study, 2.5% NaOCl solution was activated using different methods during the final irrigation, and the results were compared with those of 5.25% NaOCl solution. However, the findings indicate that the cleaning efficiency of the high concentration NaOCl solution could not be achieved by activating the low-concentration NaOCl solution using laser, ultrasonic, and intracanal heating methods during the final irrigation. Activation at both concentrations improved solution effectiveness, with Er,Cr:YSGG laser activation demonstrating more effective cleaning in the canal compared to PUI and intracanal heating methods. Notably, the difference between PUI and intracanal heating was significant. Wang et al. [21], Ozbay et al. [22], and Shahriari et al. [23] in their studies evaluating the smear removal efficiency of irrigation solutions with laser, reported that laser activation significantly enhanced solution effectiveness. Mancini et al. [24] also found that laser activation removed more smear layer compared to sonic and ultrasonic methods. Therefore, the results obtained in this study align with the existing literature.

In recent years, researchers have shown interest in increasing the efficiency of NaOCl through heating. Heating the NaOCl solution enhances its flow and reaction rate, resulting in increased antimicrobial activity and tissue dissolution effect [11, 25]. There are two methods of heating NaOCl in the root canal: extra-oral heating, where the solution is heated outside the canal, and intracanal heating, where heat carriers are used to heat the solution after it is placed in the canal. Iandolo et al. [11] reported that intracanal heating was more effective in their study comparing intracanal heating of NaOCl at 180 °C and extra-oral heating at 50 °C on root canal cleaning. Another study by Damade et al. [25] compared the amount of debris removal using intracanal and extra-orally heated NaOCl solutions with and without ultrasonic activation. They found that intracanal heating removed more debris and had a significant effect. In contrast, this study found that ultrasonic activation cleaned more debris than intracanal heating. The conflicting results between these two studies may be due to differences in methodology. Damade et al. used heated NaOCl solution during root canal expansion and shaping, while it was used in final irrigation activation in this study. In another study by Landolo et al. [12], it was reported that ultrasonic activation of heated NaOCl increased the amount of debris removal compared to ultrasonic activation of non-heated NaOCl, showing a significant difference consistent

with Damade et al.'s results. The boiling temperature of NaOCl solution ranges from 96 °C to 120 °C. In studies evaluating the effectiveness of NaOCl heating, researchers tested different temperatures. Woodmansey et al. [11] conducted their studies at 200 °C, Iandolo et al. [11, 12] at 150 °C, and Simeno et al. at 100 °C. Iandolo et al. stated that heating NaOCl solution to 200 °C, which boils at 96–120 °C, would be meaningless, and repeating it in 3 cycles at 150 °C would be sufficient. Simeone et al. [26] reported that heating the NaOCl solution up to 150 °C and repeating it in 5 cycles were sufficient, and this temperature was considered safe for the periodontal ligament. In this study, the temperature was set at 150 °C for 3 cycles based on Iandolo et al.'s study. While the results obtained from both the literature studies and this study are satisfactory, further studies, such as combining intracanal heating with ultrasonic activation, could potentially yield even better results [27].

NaOCl is commonly used as an irrigation solution in endodontic treatments due to its antibacterial activity and capacity to dissolve organic tissue. However, it does not have an effect on the inorganic components of the smear layer. Therefore, it is recommended to use proteolytic irrigants such as NaOCl in combination with chelating/calcifying agents like EDTA to remove the smear layer [28]. Two different irrigation protocols are used in endodontic clinical applications; *NaOCl-EDTA* and *NaOCl-EDTA-NaOCl* [12]. However, studies have reported that long-term use of EDTA as a final irrigation solution can lead to dentin erosion. In root canal treatments, NaOCl is used to dissolve organic tissues and for its strong antimicrobial activity, while EDTA is used to dissolve hard tissue residues and open dentinal tubules. Therefore, a final irrigation with NaOCl after EDTA is advantageous for disinfection of the opened dentinal tubules and prevention of dentin erosion caused by EDTA [2]. In this study, NaOCl was used during root canal shaping, followed by EDTA and NaOCl as the final irrigation, respectively. The aim was to evaluate the debris removal efficiency of activating NaOCl at different concentrations, as mentioned before. Only NaOCl, which was used as the final irrigation solution, was activated in this study. However, it should be noted that one limitation of this study is that only NaOCl was activated, and EDTA was not activated in the final irrigation.

Various methods are used to evaluate the cleanliness of root canals, including scanning electron microscope (SEM), optical microscope, computed tomography for pre/post instrumentation analysis, and histological analysis. However, none of these methods is considered ideal [29]. Although SEM is commonly preferred in the literature for the evaluation of the smear layer in root canals, its use has been questioned in recent years because SEM

images are two-dimensional and based on qualitative observation. Therefore, histological analysis has been used in conjunction with SEM to evaluate the amount of smear and debris in root canals, with the understanding that these two methods complement each other [30, 31]. In this study, only the amount of debris remaining in the root canals was evaluated, and the histological analysis, quantitatively assessed by two independent researchers, was chosen as the preferred method. Another limitation of this study is that the remaining smear layer on the inner walls of the root surface was not evaluated by SEM analysis.

Conclusion

The 5.25% NaOCl solution provided significantly more effective cleaning of the root canal compared to the 2.5% NaOCl solution. Regardless of the final irrigation activation method used, it increased the effectiveness of the NaOCl solution at both concentrations. The Er,Cr:YSGG laser made a significant difference compared to passive ultrasonic irrigation and intracanal heating method. Ultrasonic activation provided more effective cleaning than intracanal heating and made a significant difference. However, it should be noted although activation of the 2.5% NaOCl solution with Er,Cr:YSGG laser, ultrasonic, and intracanal heating method in the final irrigation increased its effectiveness, it was not as effective as the 5.25% NaOCl solution.

Acknowledgements

Not applicable.

Authors' contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by Nesibe Zeynep Gökkaya and Ahmet Taşan. Histological analysis was performed by Eda Açıkgöz and Fikret Altındağ. Statistical analysis and the first draft of the manuscript was written by Esin Özlek, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Availability of data and materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The use of extracted teeth was approved by the Institutional Review Board and Ethics committee of The University of Yuzuncu Yil (2020/09–07) and informed consent was obtained from all subjects and/or their legal guardian(s).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 22 December 2022 Accepted: 20 July 2023

Published online: 28 July 2023

References

- Zand V, Lotfi M, Rahim S, Mokhtari H, Kazemi A, Sakhamanesh V. A comparative scanning electron microscopic investigation of the smear layer after the use of sodium hypochlorite gel and solution forms as root canal irrigants. *J Endod.* 2010;36:343–6.
- Neelakantan P, Devaraj S, Jagannathan N. Histologic assessment of debridement of the root canal isthmus of mandibular molars by irrigant activation techniques ex vivo. *J Endod.* 2016;42(8):1268–72.
- Estrela C, Estrela CRA, Barbin EL, Spanó JCE, Marchesan MA, Pécora JD. Mechanism of action of sodium hypochlorite. *Braz Dent J.* 2022;13(2):113–7.
- Pontes F, Pontes H, Adachi P, Rodini C, Almeida D, Pinto D. Gingival and bone necrosis caused by accidental sodium hypochlorite injection instead of anaesthetic solution. *Int Endod J.* 2008;41(3):267–70.
- Stojicic S, Zivkovic S, Qian W, Zhang H, Haapasalo M. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. *J Endod.* 2010;36(9):1558–62.
- Virdee SS, Farnell DJJ, Silva MA, Camilleri J, Cooper PR, Tomson PL. The influence of irrigant activation, concentration and contact time on sodium hypochlorite penetration into root dentine: an ex vivo experiment. *Int Endod J.* 2020;53(7):986–97.
- Klyn SL, Kirkpatrick TC, Rutledge RE. In vitro comparisons of debris removal of the EndoActivator system, the F file, ultrasonic irrigation, and NaOCl irrigation alone after handrotary instrumentation in human mandibular molars. *J Endod.* 2010;36(8):1367–71.
- Nagendrababu V, Jayarama J, Suresh A, Kalyanasundaram S, Neelakantan P. Effectiveness of ultrasonically activated irrigation on root canal disinfection: a systematic review of in vitro studies. *Clin Oral Investig.* 2018;46(11):1738–44.
- de Groot SD, Verhaagen B, Versluis M, Wu M-K, Wesseling PR, van der Sluis LWM. Laser-activated irrigation within root canals: cleaning efficacy and flow visualization. *Int Endod J.* 2009;42(12):1077–83.
- Verma A, Yadav RK, Tikku AP, Chandra A, Verma P, Bharti R, et al. A randomized controlled trial of endodontic treatment using ultrasonic irrigation and laser activated irrigation to evaluate healing in chronic apical periodontitis. *J Clin Exp Dent.* 2020;12(9):e821–9.
- Iandolo A, Amato M, Dagna A, Poggio C, Abdellatif D, Franco V, et al. Intracanal heating of sodium hypochlorite: scanning electron microscope evaluation of root canal walls. *J Conserv Dent.* 2018;21(5):569–73.
- Iandolo A, Abdellatif D, Amato M, Pantaleo G, Blasi A, Franco V, et al. Dentinal tubule penetration and root canal cleanliness following ultrasonic activation of intracanal-heated sodium hypochlorite. *Aust Endod J.* 2020;46(2):204–9.
- Dey P. Decalcification of bony and hard tissue for histopathology processing. In: Dey P, editor. *Basic and Advanced Laboratory Techniques in Histopathology and Cytology*. 1st ed. Singapore: Springer; 2018. pp.35–9.
- De-Deus G, Barino B, Zamolyi RQ, Souza E, Fonseca A, Fidel S, et al. Suboptimal debridement quality produced by the single-file F2 ProTaper technique in oval-shaped canals. *J Endod.* 2010;36(11):1897–900.
- Mostafa MEHAA, El-Shrief YAI, Anous WIO, Hassan MW, Salamah FTA, El Boghdadi RM, El-Bayoumi MAA, Seyam RM, Abd-El-Kader KG, Amin SAW. Postoperative pain following endodontic irrigation using 1.3% versus 5.25% sodium hypochlorite in mandibular molars with necrotic pulps: a randomized double-blind clinical trial. *Int Endod J.* 2020;53(2):154–66.
- Del Carpio-Perochena A, Bramente CM, Duarte MH, Bombarda De Andrade F. Effect of temperature, concentration and contact time of sodium hypochlorite on the treatment and revitalization of oral biofilms. *J Dent Res Dent Clin Dent Prospect.* 2015;9(4):209–15.
- Siqueira JF, Rôças IN, Favieri A, Lima KC. Chemomechanical reduction of the bacterial population in the root canal after instrumentation and irrigation with 1%, 2.5%, and 5.25% sodium hypochlorite. *J Endod.* 2000;26(6):331–4.
- Ayhan H, Sultan N, Cirak M, Ruhi MZ, Bodur H. Antimicrobial effects of various endodontic irrigants on selected microorganisms. *Int Endod J.* 1999;32(2):99–102.
- Baumgartner JC, Cuenin PR. Efficacy of several concentrations of sodium hypochlorite for root canal irrigation. *J Endod.* 1992;18(12):605–12.
- Goldsmith M, Gulabivala K, Knowles JC. The effect of sodium hypochlorite irrigant concentration on tooth surface strain. *J Endod.* 2002;28(8):575–9.
- Wang X, Cheng X, Liu X, Yu Q, He W. Effect of laser-activated irrigations on smear layer removal from the root canal Wall. *Photomed Laser Surg.* 2017;35(12):688–94.
- Ozbay Y, Erdemir A. Effect of several laser systems on removal of smear layer with a variety of irrigation solutions. *Microsc Res Tech.* 2018;81(10):1214–22.
- Shahriari S, Kasraei S, Roshanaei G, Karkeabadi H, Davanloo H. Efficacy of sodium hypochlorite activated with laser in intracanal smear layer removal: An SEM Study. *J Lasers Med Sci.* 2017;8(1):36–41.
- Mancini M, Cerroni L, Palopoli P, Olivi G, Olivi M, Buoni C, et al. FESEM evaluation of smear layer removal from conservatively shaped canals: laser activated irrigation (PIPS and SWEEPS) compared to sonic and passive ultrasonic activation: an ex vivo study. *BMC Oral Health.* 2021;21:1–10.
- Damade Y, Kabir R, Gaddalay S, Deshpande S, Gite S, Bambale S, et al. Root canal debridement efficacy of heated sodium hypochlorite in conjunction with passive ultrasonic agitation: An ex vivo study. *J Dent Res Dent Clin Dent Prospects.* 2020;14(4):235–8.
- Simeone M, Valletta A, Giudice A, Di Lorenzo P, Iandolo A. The activation of irrigation solutions in Endodontics: a perfected technique. *G Ital Endod.* 2015;29(2):65–9.
- Di Spirito F, Pisano M, Caggiano M, Bhasin P, Lo Giudice R, Abdellatif D. Root Canal Cleaning after Different Irrigation Techniques: An Ex Vivo Analysis. *Medicina (Kaunas).* 2022;58(2):193.
- Voegeli G, Bello ED, Mekki M, Machtout P, Bouillaguet S. Effect of a modified irrigation protocol on the cleanliness of moderately curved canals. *Eur J Dent.* 2021;15(1):90–5.
- Passarinho-Neto JG, Marchesan MA, Ferreira RB, Silva RG, Silva-Souso YT, Sousa-Neto MD. In vitro evaluation of endodontic debris removal as obtained by rotary instrumentation coupled with ultrasonic irrigation. *Aust Endod J.* 2006;32(3):123–8.
- Al-Ali M, Sathorn C, Parashos P. Root canal debridement efficacy of different final irrigation protocols. *Int Endod J.* 2012;45(10):898–906.
- Orlowski NB, Schimdt TF, Teixeira CDS, Garcia LDFR, Savaris JM, Tay FR, Bortoluzzi EA. Smear layer removal using passive ultrasonic irrigation and different concentrations of sodium hypochlorite. *J Endod.* 2022;46(11):1738–44.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

