ORIGINAL RESEARCH ORİJİNAL ARAŞTIRMA

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The Impact of Intracanal Heating and Irrigation Solution Activation on Organic Tissue Removal from Internal Resorption Cavities: An *in vitro* Study

İnternal Rezorpsiyon Kavitesinden Organik Doku Uzaklaştırılmasına İntrakanal Isıtma ve İrrigasyon Solüsyonu Aktivasyonunun Etkisi: *in vitro* Çalışma

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This study was presented as an oral presentation at FDI World Dental Congress, September 12-15, 2024, İstanbul, Türkiye.

ABSTRACT Objective: This study aimed to compare various activation techniques for removing organic tissue from simulated internal resorption cavities, utilizing sodium hypochlorite (NaOCl) at both intracanal heated and room temperature. **Material and Methods:** A total of 120 mandibular premolar teeth were horizontally divided into two parts, and internal resorption cavities were created in each part. Bovine muscle tissue samples were inserted into resorption cavities. Roots were reassembled, and teeth divided into two groups (n=60) by irrigation temperature (room temperature, intracanal heated). Each of the two groups was further divided into 5 subgroups for irrigation activation purposes: standard needle irrigation (SNI), EndoActivator (EA), EDDY, passive ultrasonic irrigation, XP-endo Finisher (XPF). After irrigation protocols, organic tissue remnants in resorption cavities were scored and differences among tissue removal scores were analyzed. **Results:** XPF demonstrated superior organic tissue removal compared to SNI in both room temperature and intracanal heated NaOCl groups. All activation groups showed no significant difference in the efficacy of organic tissue removal between NaOCl at room temperature and when heated intracanal. **Conclusion:** The XPF was found to be the most effective method for removing organic tissue from internal resorption cavities. Intracanal heating NaOCl did not have any significant effect on removing organic tissue from internal resorption cavities.

Keywords: Sodium hypochlorite; root canal irrigants; root resorption

ÖZET Amaç: Bu çalışma ile simüle edilmiş internal rezorpsiyon kavitelerinden organik dokunun uzaklaştırılması için hem kanal içinde ısıtılan hem de oda sıcaklığındaki sodyum hipoklorite (NaOCl) uygulanan aktivasyon tekniklerinin karşılaştırılması amaçlanmıştır. **Gereç ve Yöntemler:** Toplamda 120 mandibular premolar diş yatay olarak 2 parçaya bölünmüş ve her parçaya internal rezorpsiyon kaviteleri oluşturulmuştur. Rezorpsiyon kavitelerine sığır kas dokusu yerleştirilmiş ve kökler tekrar birleştirilmiştir. Dişler, irrigasyon sıcaklığına göre 2 gruba (n=60) ayrılmıştır (oda sıcaklığı, intrakanal ısıtma). Her iki grup, irrigasyon aktivasyon yöntemlerine göre 5 alt gruba ayrılmıştır: standart iğne irrigasyonu [standard needle irrigation (SNI)], EndoActivator (EA), EDDY, pasif ultrasonik irrigasyon, XP-endo Finisher (XPF). İrrigasyon protokollerinden sonra rezorpsiyon kavitelerinde kalan organik doku kalıntıları değerlendirilmiş ve doku uzaklaştırma skorları arasındaki farklar analiz edilmiştir. **Bulgular:** XPF hem oda sıcaklığındaki hem de intrakanal ısıtılmış NaOCl gruplarında SNI'ya kıyasla daha üstün organik doku uzaklaştırma performansı göstermiştir. Tüm aktivasyon gruplarında, NaOCl'nin oda sıcaklığı ve intrakanal ısıtma arasındaki organik doku uzaklaştırma etkinliği açısından anlamlı bir fark bulunmamıştır. **Sonuç:** XPF internal rezorpsiyon kavitelerinden organik doku uzaklaştırmada en etkili yöntem olarak bulunmuştur. NaOCl'nin kanal içi ısıtılmasının internal rezorpsiyon kavitesinden organik doku uzaklaştırılması üzerinde önemli bir etkisi olmamıştır.

Anahtar Kelimeler: Sodyum hipoklorit; kök kanalı sulayıcıları; kök rezorpsiyonu

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Internal root resorption is a chronic inflammatory process that in the progressive destruction of dentin.[1] The irregular areas of resorption in affected teeth complicate the chemomechanical preparation and filling of canals during root canal treatment. Effectively removing the inflamed pulpal and granulation tissue that fills the resorption cavity is crucial for managing cases of internal root resorption.[2]

Sodium hypochlorite (NaOCl) is the main irrigation solution preferred in root canal treatment due to its antibacterial and organic tissue-dissolving efficacy.[3,4] The activation of irrigation solutions is a key method for enhancing the antibacterial and antibiofilm activities of root canal irrigants extend beyond the root canal itself, effectively targeting the anatomical complexities of the root canal system and the dentinal tubules.[5] The activation of NaOCl increases its capacity to dissolve organic tissue. Sonic, ultrasonic devices, and lasers have been used to enhance this dissolution capacity.[6-8]

Increasing the temperature of NaOCl can enhance its efficacy and organic tissue dissolution capacity.[9-13] The foundational research on heating NaOCl dates back to the 1980s, where it was observed that raising the temperature from 22°C to 37°C enhanced its tissue dissolution properties.[11] Cunningham and Joseph noted that increased temperature also boosts the antibacterial efficacy of hypochlorite.[12] Elio Berutti and Marini discussed the action of hypochlorite at various temperatures, indicating that NaOCl at higher temperatures is more effective in removing the smear layer.[13] NaOCl can be heated before introduction into the canal, either by preheating in a syringe or by using a heat source such as System B within the canal.[10,14-16] Although preheating NaOCl solution before its application to the canal is a commonly used method, it has been observed that the temperature of NaOCl quickly returns to body temperature with this technique.[9-11,14,17,18] It has been reported that intracanal-heated NaOCl is superior to preheated NaOCl in terms of smear layer removal, debris elimination, and antimicrobial efficacy.[15,19,20]

The EndoActivator (EA) (Dentsply Sirona, York, USA) is a device designed for sonic activation of irrigation solutions in root canals. It features three polymer tips (15/02, 25/04, 35/04) that oscillate at sonic frequencies, promoting effective irrigant agitation without damaging the dentinal walls.[21,22] The EDDY (VDW, Munich, Germany) is a polymer tips that operate at sonic frequencies (5,000-6,000 Hz) via an air scaler, facilitating the homogeneous distribution of irrigants throughout the canal system without damaging the root canal walls.[22] Passive ultrasonic irrigation (PUI) utilizes metallic tips that oscillate at ultrasonic frequencies (25-30 kHz), creating microstreaming that enhances the movement of irrigants and debris removal within the canal.[22,23] The XP-endo Finisher (XPF) (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) is an innovative instrument designed as a final step in the disinfection protocol, offering an advanced approach to cleaning root canals with complex anatomical features. Made from nickel-titanium (NiTi) MaxWire alloy, the XPF takes advantage of the shape-memory properties of NiTi, transitioning from a straight shape at room temperature (martensite phase) to a spoon-like shape when exposed to body temperature (austenite phase), allowing it to adapt to the unique morphology of the root canal. Its non-tapered design (available in sizes ISO 025 and ISO 30) preserves the natural anatomy of the root canal while efficiently cleaning irregular areas due to its enhanced flexibility and ability to expand, adapting three-dimensionally to the canal.[24]

The effectiveness of irrigation activation systems in removing organic tissue from internal resorption cavities has been evaluated in the literature.[6,25-27] Studies have shown that PUI is more effective in removing organic tissue compared to groups without activation.[25,27] Koc et al. reported that the effects of PUI and sonic activation were similar in terms of organic tissue removal.[26] Ulusoy et al. found that the XPF method was more effective than PUI.[6] However, no study in the literature has evaluated the effect of irrigation solution temperature and the methods of heating the solution on the removal of organic tissue from internal resorption cavities

The aim of our study was to assess the effect of intracanal heating and activation of NaOCl on the removal of organic tissue from artificially created internal resorption cavities. The first null hypothesis of the study is that the temperature of NaOCl will not cause a significant difference in the effectiveness of organic tissue removal from internal resorption cavities. The second null hypothesis is that activation of NaOCl will not result in a significant difference in the effectiveness of organic tissue removal.

MATERIAL AND METHODS

The study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol received approval from the Çanakkale Onsekiz Mart University Non-Invasive Clinical Research Ethics Committee (date: December 20, 2023, no: 2023/16-16). The necessary sample size for the study was established using data from a previous study, calculated with the G*Power 3.1 software package (Heinrich Heine University, Düsseldorf, Germany). A minimum total sample size of 120 (n=12) was determined based on the F test family, with an effect size of 0.387, an alpha error rate of 0.05, and a power level of 0.80.[27]

The study included 120 mandibular human premolar teeth. The inclusion criteria consisted of single-rooted, single-canal teeth that were free of caries and restorations. Teeth with cracks or resorption were excluded based on the exclusion criteria. The crowns of the teeth were shortened to standardize the root lengths to 20 mm for all specimens, and the root canals were then prepared using a ProTaper Next X5 file (PTN; Dentsply, Maillefer, Ballaigues, Switzerland). After each instrument use, irrigation with 2 mL of 2.5% NaOCl (Chloraxid, Cerkamed, Poland) was performed, and 5 mL of 2.5% NaOCl and 5 mL 17% EDTA (Endo-Solution, Cerkamed, Poland) was applied for the final irrigation. A circumferential groove was created around the root, 10 mm from the coronal surface and perpendicular to its long axis, and then the root was split into two fragments using a hammer and chisel. Two root fragments, one upper and one lower, were obtained. Resorption cavities, 2 mm in diameter and 1 mm deep, were subsequently formed in each root fragment using a diamond round bur. The debris generated from the internal root resorption cavity preparation was removed in sequence by washing with NaOCl, followed by EDTA, and then rinsing with distilled water, using a microbrush. A sample of bovine muscle tissue obtained from the butcher was placed in two semicircular cavities of each root (Figure 1). In order to distinguish the remaining residual organic tissue within the samples after activation, methylene blue (Canal detector, Cerkamed, Stalowa Wola, Poland) was mixed with the bovine muscle tissue before being placed into the cavity. The root sections containing the tissue samples were brought together and bonded using cyanoacrylate.

120 samples were divided into 2 main groups based on the NaOCl temperature used (room temperature, intracanal heated). In the room temperature group, irrigation was performed with 2.5% NaOCl at room temperature. In the intracanal heated group, after irrigation with 2 mL of 2.5% NaOCl at room temperature, a size 50.04 heat plugger (Diadent, Chongju, Korea) was inserted into the canal, and the device was set to 230°C to heat the irrigant inside the root canal. In the intracanal heated group, the heating process was repeated before each activation. Each main group was further divided into 5 subgroups based on the irrigation activation method applied.

Standart needle irrigation (SNI): In room temperature-SNI group irrigation with 6 mL of 2.5% NaOCl was performed using a 31-gauge, 27 mm long

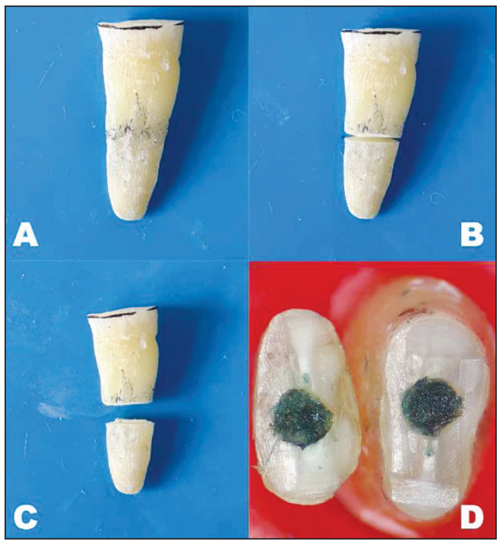

FIGURE 1: Stages of preparing the sample. **A)** Decoronated sample; **B)** A circumferential groove created around the root; **C)** Two fragments of the sample; **D)** Organic tissue within the simulated resorption cavity.

double-sided port irrigation needle (NaviTip; Ultradent, South Jordan, UT), positioned 2 mm short of the apex with up-and-down movements.

In the intracanal heated-SNI group, after completing the procedure as in the room temperature-SNI group, the NaOCl solution inside the canal was heated for 10 seconds with a heat plugger.

PUI: In the room temperature-PUI group, after irrigation with 2 mL of 2.5% NaOCl, ultrasonic activation was performed for 20 seconds. A 21 mm ultrasonic tip (Woodpecker, Japan) was used with the ultrasonic device (VDW Ultra, VDW, Munich, Germany) set to 30% power, applying up-and-down movements 2 mm from the apex. This procedure was repeated three times.

In the intracanal heated-PUI group, after applying 2 mL of 2.5% NaOCl to the canal at room temperature, the solution was heated for 10 seconds using a heat plugger. Then, the same procedure as in the room temperature-PUI group was performed. This process was repeated three times.

EA: In the room temperature-EA group, after irrigation with 2 mL of 2.5% NaOCl, a medium-sized polymer tip was attached to the EA used for 20 seconds, 2 mm short of the working length. This procedure was repeated three times.

In the intracanal heated-EA group, after applying 2 mL of 2.5% NaOCl to the canal at room temperature, the solution was heated for 10 seconds using a heat plugger. Then, the same procedure as in the room temperature-EA group was performed. This process was repeated three times.

EDDY: In the room temperature-EDDY group, after irrigating with 2 mL of 2.5% NaOCl, activation was carried out by connecting a sonic activation tip (28 mm in length, size 25/0.04) to an air cavitron (TA-200; Micron, Tokyo, Japan). The tip was positioned 2 mm short of the working length and activated for 20 seconds. This process was repeated three times.

In the intracanal heated-EDDY group, after applying 2 mL of 2.5% NaOCl to the canal at room temperature, the solution was heated for 10 seconds using a heat plugger. Then, the same procedure as in the room temperature-EDDY group was performed. This process was repeated three times.

XPF: In the room temperature-XPF group, after irrigation with 2 mL of 2.5% NaOCl, the XPF file was inserted into the root canal and activated with a rotation motion at 1000 rpm and 1 Ncm torque setting for 20 seconds. This process was repeated three times.

In the intracanal heated-XPF group, after applying 2 mL of 2.5% NaOCl to the canal at room temperature, the solution was heated for 10 seconds using a heat plugger. The same procedure as in the room temperature-XPF group was then performed, repeated three times.

The root pieces were re-separated, and the simulated resorption cavities in each half were examined using a 17x magnification dental operating microscope (Zumax 2380, Zumax). Digital images were captured for each specimen. Two trained clinicians, blinded to the experimental groups, independently evaluated each image using the classification system (Figure 2).[28]

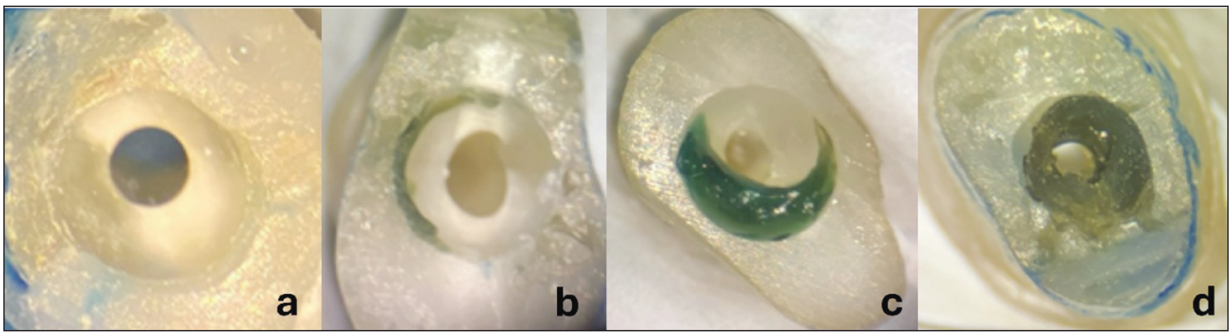

FIGURE 2: Presentation of the remaining organic tissue score distribution. **a)** score 0; **b)** score 1; **c)** score 2; **d)** score 3.

Score 0: The cavity is entirely empty.

Score 1: Less than 50% of the cavity is filled.

Score 2: More than 50% of the cavity is filled.

Score 3: The cavity is fully filled.

RESULTS

The inter-examiner reliability for each evaluation was confirmed using the Kappa test. The Shapiro-Wilk test indicated that the data did not follow a normal distribution. Differences in organic tissue removal scores across the tested groups were assessed using the Kruskal-Wallis H and Mann-Whitney U tests. The significance level was set at 0.05, and all statistical analyses were conducted with SPSS 21.0 software (SPSS Inc., Chicago, IL, USA).

The Kappa coefficient test demonstrated a strong level of concordance between the evaluators (0.865).

Figure 3 details the distribution of removal scores in all experimental groups. None of the tested groups were able to remove organic tissue from resorption cavities completely. Table 1 shows the median (min-max) values of residual organic tissue scores for the activation and heating groups. There was a statistically significant difference in organic tissue removal scores among activation methods in both heat groups (p=0.027 for room temperature, p=0.05 for intracanal heated). In the room temperature group, XPF removed significantly more organic tissue than SNI (p=0.017), while no significant differences were found among the other activation methods. In the intracanal heated group, XPF removed significantly more organic tissue than both SNI and EA (p=0.014, p=0.006, respectively), with no significant differences observed among the other activation methods. Additionally, no significant difference in organic tissue removal was observed between room temperature and intracanal heated NaOCl across all activation groups.

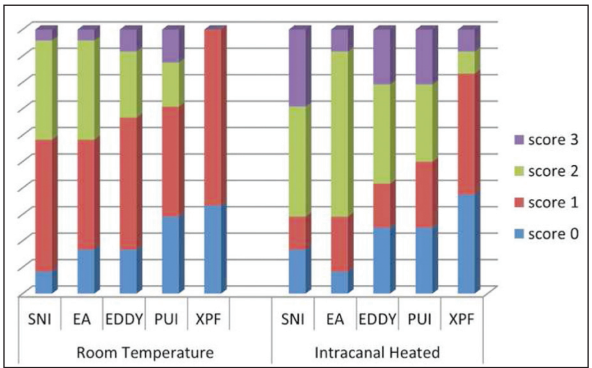

FIGURE 3: Score distribution chart for the activation and temperature groups. SNI: Standard needle irrigation; EA: EndoActivator; PUI: Passive ultrasonic irrigation; XPF: XP-endo Finisher.

TABLE 1: Residual organic tissue scoring distributions.

	Room temperature	Intracanal heated	p value
SNI	1 (0-3)[a]	2 (0-3)[a]	0.052
EA	1 (0-3)[ab]	2 (0-3)[a]	0.055
EDDY	1 (0-3)[ab]	2 (0-3)[ab]	0.283
PUI	1 (0-3)[ab]	1.5 (0-3)[ab]	0.279
XPF	1 (0-1)[b]	1 (0-3)[b]	0.640
p value	0.027	0.05	

Median (Min-Max) distributions of residual tissue scoring. Lower case letters (a-b) indicate significance within the column. SNI: Standard needle irrigation; EA: EndoActivator; PUI: Passive ultrasonic irrigation; XPF: XP-endo Finisher.

DISCUSSION

Eliminating inflamed pulp and granulation tissue from the resorption cavity is vital for the successful treatment of internal root resorption cases.[2] In our study, the complete removal of organic tissue from the internal resorption cavity could not be achieved with any method. The first null hypothesis of the study, which stated that the temperature of NaOCl would not cause a significant difference in the effectiveness of organic tissue removal from internal resorption cavities, was accepted. No significant difference was found in organic tissue removal between intracanal heating and room temperature. The second null hypothesis of the study, which stated that the activation of NaOCl would not cause a significant difference in the effectiveness of organic tissue removal, was rejected. It was found in our study that the XPF file system was the most effective method for removing organic tissue compared to standard needle irrigation. Similarly, Ulusoy et al. reported that the XPF method was superior in terms of organic tissue removal from internal resorption cavities, demonstrating greater tissue weight loss than the other tested activation protocols.[6]

Elnaghy et al. demonstrated that the XPF file significantly improved tissue removal in challenging canal regions where conventional instruments often fail to reach.[29] Additionally, it has been reported that XPF is more effective than PUI and SNI in removing biofilm from hard-to-reach areas of the root canal system.[30] In these studies focusing on the removal of biofilm or debris from the root canal system, XPF was also found to be an effective method, similar to our findings.

The effectiveness of various irrigation activation methods in removing organic tissue from internal resorption cavities has been a focus of significant research.[6,25-27] The use of PUI has been reported to enhance the effectiveness of organic tissue removal from internal resorption cavities.[25] According to the study by Monteiro et al., mechanical activation with Easy Clean was found to be more effective than PUI for removing organic tissue from internal resorption cavities.[27] In two other studies comparing sonic and ultrasonic activation, no significant differences were found between these activation systems.[7,26] Similarly, our study revealed comparable findings regarding the effectiveness of sonic and ultrasonic systems. XPF facilitates root canal cleaning by adapting to the canal walls with its unique mechanical properies and has been evaluated in studies related to internal resorption.[6] In addition, studies assessing the effectiveness of organic tissue removal from teeth with internal resorption have generally focused on the efficacy of PUI.[6,25-27] However, no studies have compared sonic and ultrasonic activation systems with XPF, a mechanical system. Therefore, the effectiveness of these methods in removing organic tissue from internal resorption cavities at different irrigation solution temperatures has been investigated.

When examining the studies in which internal resorption cavities were artificially created, it was found that in some of the studies, the resorption cavities were created after the teeth were divided into halves horizontally while in another group, the resorption cavities were created by dividing the teeth into halves longitudinally.[6,25-27,31] In this study, due to the simplicity of splitting the teeth, they were divided horizontally into two parts, similar to previous studies.[25,31] Additionally, creating the simulated resorption cavity, placing the simulated organic tissue, and evaluating the remaining organic tissue were simpler using this method.

Recent studies have found that heating NaOCl increases tissue-dissolving activty due to enhanced chemical reactivity and faster breakdown of organic material.[32] Studies have emphasize the superiority of intracanal heating over preheating in terms of smear layer removal, debris elimination, and antimicrobial efficacy.[15,19,20] Preheated solutions lose temperature as soon as they are injected into the canal, leading to reduced efficacy, while intracanal heating maintains a constant, elevated temperature throughout the irrigation process, thereby maximizing the tissue-dissolving potential of NaOCl.[17,18] According to Jaiswal et al., intracanal heating resulted in significantly better dissolution of pulp tissue compared to extracanal heating.[33] For these reasons, intracanal heating was chosen in our study, as it ensures more consistent heating, which is crucial for optimal tissue removal.

Unlike earlier studies, that demonstrated significant improvements in tissue dissolution with heated NaOCl, our results showed no significant difference between intracanal heated NaOCl and room-temperature NaOCl for organic tissue removal.[9,10,32,33] There are two likely explanations for this discrepancy. First, evaporation of the irrigation solution: in our study, we observed that heating the NaOCl led to rapid evaporation of the solution, which may have contributed to the dehydration of the organic tissue. As the tissue dried, it became more adherent to the canal walls, making it difficult to dissolve and remove. Second, reduced liquid volume due to decoronation; the decoronation procedure in our study created a smaller chamber for the irrigants, leading to a smaller liquid pool. This was further compounded by the fact that the heating device reduced the solution volume when placed inside the cavity.

In earlier studies, pre- and post-procedure tissue weights were compared by weighing the tissue to determine the loss of organic material.[6,25-27,34] However, during our pilot study, we observed inconsistencies in the sample weights due to the evaporation of irrigants absorbed into both the organic tissue and the tooth structure. This evaporation led to inconsistent weight measurements, which would have skewed our results. Christensen et al. have noted similar challenges when attempting to use gravimetric methods for assessing tissue dissolution in endodontic studies.[34] Given these complications, we opted for visual analysis, which provided a more consistent and reliable method for evaluating tissue removal without the complications of solution evaporation.

The limitation of this study is that the use of bovine muscle tissue in place of granulation tissue in the internal resorption cavity does not fully mimic granulation tissue, which resembles periodontal ligament tissues with relatively more cells and fibrous content and fewer blood vessels compared to normal pulp tissue.[35]

CONCLUSION

When examining the effectiveness of organic tissue removal from internal resorption cavities, only the XPF method showed advantages over traditional irrigation methods. Intracanal heating the irrigation solution did not provide any benefits compared to its use at room temperature. The 10 second heating time in the root canal may make it more difficult to remove organic tissue due to the evaporation of the solution and the subsequent drying of the organic tissue. Therefore, using a shorter heating time for the solution or utilizing solutions heated outside the root canal may yield better clinical results. Further studies are needed to investigate this issue.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Öznur Sarıyılmaz, Evren Sarıyılmaz; **Design:** Öznur Sarıyılmaz, Emek Bayındır; **Control/Supervision:** Öznur Sarıyılmaz, Evren Sarıyılmaz; **Data Collection and/or Processing:** Emek Bayındır, Kardelen Yıldırım, Mahmut Can Tokaş; **Analysis and/or Interpretation:** Öznur Sarıyılmaz, Evren Sarıyılmaz; **Literature Review:** Emek Bayındır, Öznur Sarıyılmaz, Kardelen Yıldırım, Mahmut Can Tokaş; **Writing the Article:** Öznur Sarıyılmaz, Emek Bayındır; **Critical Review:** Evren Sarıyılmaz; **References and Fundings:** Öznur Sarıyılmaz, Emek Bayındır; **Materials:** Öznur Sarıyılmaz, Evren Sarıyılmaz.*

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