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Original Article

Comparisons of the smear layer removal efficacy of dual-action irrigants and different activation techniques

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Abstract *Background/purpose:* Dual-action root canal irrigants containing disinfectant(s) and chelator(s) are expected to enhance root canal cleaning efficiency. This study aimed to evaluate the effectiveness of these irrigants and different activation techniques on smear layer removal.
Materials and methods: Seventy-six extracted human mandibular premolars were root canal-prepared up to an apical size of #40/0.06, grouped and irrigated as follows, and the smear layer on each third of the canal wall was evaluated using scanning electron microscopy. In Experiment 1, syringe irrigation (SI) was carried out using a dual-action irrigant (Triton or SmearOFF) or a combination of 17% ethylenediaminetetraacetic acid (EDTA) and 6% sodium hypochlorite (NaOCl) (n = 12, each). In Experiment 2, Triton was activated by laser-activated irrigation (LAI) with a novel Er:YAG laser equipment (Adverl SH, Morita Manufacturing, Kyoto, Japan), an LAI protocol called shockwave-enhanced emission photoacoustic streaming (SWEEPS), or ultrasonic-activated irrigation (UAI), and irrigated with SI (n = 10, each).
Results: In Experiment 1, the Triton group demonstrated significantly better smear layer scores than the EDTA and NaOCl combination group across all canal thirds ($P < 0.05$). In Experiment 2, using Triton as the irrigant, the LAI and SWEEPS groups exhibited significantly superior smear layer scores compared to the UAI group across all canal thirds ($P < 0.05$).
Conclusion: Triton was more effective than the combination of EDTA and NaOCl in removing the smear layer across all root canal thirds. The efficacy of Triton was further enhanced by activation with LAI and SWEEPS.

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Introduction

The essential triad of root canal treatments includes shaping, cleaning, and filling. Successful endodontic treatment depends on the integration of these elements. Chemical cleaning is crucial for disinfection and smear layer removal.[1] The smear layer is created on the canal wall during the shaping process and may contain pulp remnants, dentin debris, blood cells, and bacteria. The smear layer covers the dentinal tubules, impedes penetration by irrigants and medications, and hinders the removal of infectious substances.[2] The smear layer can also decrease the seal between the root canal sealer and canal walls, thus increasing micro-leakage and treatment failure risk.[3] Therefore, removing the smear layer is recommended to improve disinfection and root canal filling quality.[4]

Sodium hypochlorite (NaOCl) can dissolve organic materials and demonstrate antimicrobial properties. Ethylenediaminetetraacetic acid (EDTA), a chelating agent, is effective at removing inorganic components. Because the smear layer comprises both organic and inorganic components, its removal often employs a combination of NaOCl and EDTA.[5]

Recently, dual-action root canal irrigants combining disinfectant(s) and chelating agent(s) into a single solution have emerged as a 2-in-1 concept. This approach aims to reduce treatment time and enhance the effectiveness of root canal treatments.[6]

One such product, SmearOFF (Vista Dental Products, Racine, WI, USA), combines 18% EDTA and <1% chlorhexidine gluconate (CHX) (Table 1) for final root canal irrigation. This irrigant showed higher sealer penetration and more patent dentinal tubules compared to the sequential use of EDTA and CHX.[7] A previous study indicated that SmearOFF was more effective at removing the smear layer than other 2-in-1 solutions, such as QMix (Dentsply Sirona, Charlotte, NC, USA) and Irritrol (Essential Dental Systems, Hackensack, NJ, USA).[6]

Conversely, Triton (Brasseler, Savannah, GA, USA) is a novel irrigant developed as an all-in-one, dual-action root canal irrigant. This irrigant works differently by avoiding EDTA and CHX, instead opting to combine the benefits of citric acid, NaOCl, pH modifiers, and surfactants (Table 1).

Conventional syringe irrigation (SI) is a widely performed procedure using needles and syringes. However, SI can only deliver irrigant fluid up to 0.1–1 mm past the needle tip.[8] Because of the complex morphology of the root canal, the irrigant often fails to reach the apical thirds of the canal, and vapor lock can occur in intricate areas, thus limiting the penetration depth of static irrigation.[9]

Therefore, several activation methods have been described to improve irrigant distribution and effectiveness.[10–18] Among these, ultrasonic-activated irrigation (UAI), a representative irrigant activation method, generates cavitation and acoustic streaming, which enhance the irrigant flushing and aid in removing debris and planktonic bacteria from the root canal.[19]

Laser-activated irrigation (LAI) is increasingly being used to activate irrigants in root canal irrigation because of its high efficiency.[10–16] An Er:YAG laser, in particular, generates rapid fluid movement with secondary cavitation effects when vapor bubbles collapse.[12] This turbulent photoacoustic streaming can effectively clean complex canal anatomies, including isthmuses,[13] lateral canals,[14] apical areas beyond canal ledges,[15] and areas beyond fractured instruments.[16] Recently, a novel laser irrigation protocol known as shock-wave enhanced emission photoacoustic streaming (SWEEPS) has been used to clean root canals.[17] SWEEPS generates a pair of laser micro pulses, with the second pulse timed optimally after the first to increase pressure and accelerate the collapse of the main laser-induced bubbles within even the narrowest canals.[18] Additionally, the novel Er:YAG laser equipment, Adverl SH (Morita Manufacturing, Kyoto, Japan), which launched in 2024, also showed superior cleaning efficacies in complex anatomy.[20] This equipment was designed to enable shorter pulse durations and deliver a higher peak power.

However, these irrigant activation techniques are complex procedures, as they involve the sequential activation of multiple irrigants.[21,22] Therefore, it would be clinically beneficial if a dual-action irrigant activation method could achieve the cleaning effect in a single step.

Table 1 Composition of dual-action irrigants.

Irrigants	Chemical composition	Lot No.
SmearOFF	Tetrasodium ethylenediaminetetraacetate dihydrate (18%), chlorhexidine gluconate (<1%), sodium hydroxide (<1%), and surfactant blend (<1%).	20230138
Triton	Part A:1,2,4-Butanetricarboxylic acid, 2-phosphono- (<15%), citric acid (<2%), sodium dodecyl benzenesulfonate (<2%), alcohols C9-11 ethoxylated liquids (<2%), polyethylene glycol 4-(tert-octylphenyl) ether liquid (<2%), sodium lauryl sulfate (<2%), 2-ethylhexyl sodium sulfate (<2%), sodium cumenesulphonate (<2%), and sodium hydroxide (<1%). Part B: Sodium hypochlorite (<10%), and sodium hydroxide (<2%).	20222938

To the best of our knowledge, no studies have compared the efficiency of Triton with other dual-action irrigants or evaluated Triton activation using different techniques for smear layer removal. Therefore, this study aimed to compare the effectiveness of smear layer removal among (1) different dual-action irrigants and (2) dual-action irrigants activated using various techniques. The null hypothesis was that there were no differences in the efficacy of smear layer removal among (1) irrigants tested and (2) irrigant activation techniques.

Materials and methods

Sample selection

The sample size was determined using G*Power software (version 3.1.9; Heinrich-Heine Universität, Düsseldorf, Germany). Based on a previous study,[16] sample sizes of 12 per group for Experiment 1 and 10 per group for Experiment 2 were obtained with an effect size of 0.7, a significance level of 0.05, and 95% power.

A total of 76 extracted human mandibular premolars of similar lengths have been selected with the approval of the Institutional Review Board of Tokyo Medical and Dental University (No. D2023-029). All teeth were confirmed using micro-computed tomography (inspeXio SMX-100CT PLUS, Shimadzu, Kyoto, Japan) to ensure having only a single, straight root and root canal ($<10^\circ$ in Schneider's method[23]), absence of lateral canals, calcification, immature apex, and any signs of caries, cracks, previous root canal treatments, or restorations.

Root canal preparation

After the access cavity was prepared, a #10 K-file (Zipperer, VDW, Munich, Germany) was inserted into the root canal until the tip passed through the foramen. The working length (WL) was 1 mm short of the anatomical foramen. To simulate a clinical situation, the apex of each tooth was sealed with sticky wax.

The teeth were prepared using Vortex Blue nickel-titanium rotary files (Dentsply Sirona, Ballaigues, Switzerland) up to an apical size of #40/0.06. The canal was irrigated with 2 mL 6% NaOCl (Dental Antiformin; Nippon Shika Yakuhin, Shimonoseki, Japan) with a 2.5 mL syringe (Nipro, Osaka, Japan) and a 27-G irrigation needle (Nipro) between each file change. Finally, 2.5 mL 17% EDTA was added for 30 s and left in the root canal for 30 s before rinsing with 2.5 mL distilled water for 30 s.

Final root canal irrigation protocols

Experiment 1

Thirty-six samples were randomly assigned into three groups of 12 samples each. The experimental groups (n = 12) underwent SI using either Triton, SmearOFF, or a combination of 17% EDTA and 6% NaOCl (EDTA & NaOCl). SI was carried out using a 2.5 mL syringe (Nipro) with a 27G irrigation needle (Nipro), which was inserted 1 mm short of the WL and moved up and down. The root canals were irrigated with 2.5 mL of the respective irrigant (Triton or SmearOFF) for 30 s and left in the root canal for 30 s.

In the EDTA & NaOCl group, after irrigating with 2.5 mL of EDTA, further irrigated with 5 mL of distilled water to neutralize the EDTA, followed by 2.5 mL NaOCl for another 30 s. This NaOCl irrigation sequence was repeated three times.

Finally, all the samples were rinsed with 2.5 mL of distilled water for 30 s to remove residual irrigants.

Experiment 2

Experiment 2 was designed to compare the efficacy of Triton irrigant activation protocols based on its superior cleaning results in Experiment 1. Forty samples were randomly assigned into four groups (n = 10). Triton was activated by LAI, SWEEPS, or UAI and irrigated with SI.

The LAI group underwent activation using an Er:YAG laser (AdvErL SH; Morita Manufacturing, Kyoto, Japan) with a flat tip (C400F; Morita Manufacturing). The irradiation settings were 30 mJ, 20 Hz, and the pulse duration set at the Hard mode (applied voltage pulse duration: 300 μs, actual output pulse duration level: 60 μs), with air/water turned off. The tips of each laser device were kept stationary in the pulp chamber. Each group received 2.5 mL of Triton delivered with a 27-G needle for 30 s, followed by a 30-s resting phase.

In the SWEEPS group, an Er:YAG laser (LightWalker; Fotona, Ljubljana, Slovenia) equipped with a flat tip (Flat SWEEPS 400/14 tip; Fotona) was employed. The laser parameters were set at 20 mJ and 15 Hz in the AUTOSWEEPS mode for 30 s, followed by a 30-s resting phase.

In the UAI group, Triton was activated using an ultrasonic device (Osada ENAC, OE-11W, Osada, Tokyo, Japan) set at power level 3 for 30 s, followed by a 30 s resting phase. An ultrasonic file (U-file #15, Pierce, Tokyo, Japan) was positioned 2 mm short of the WL.

In the SI group, the procedure used in Experiment 1 was followed to irrigate with Triton.

Finally, the samples were irrigated with distilled water (2.5 mL for 30 s) according to the methods of each group.

Scanning electron microscopy (SEM)

After irrigation, all specimens were split longitudinally into halves. One-half of each specimen was evaluated using SEM (JSM-7900F, JEOL, Tokyo, Japan). Three images per sample were captured at a magnification of 1000×, with each image representing the apical, middle, and coronal areas. Three observers with five, three, and two years of SEM research experience in endodontics were blinded to the experimental groups, and evaluated the smear layers on SEM images using Hülsmann's scoring system (Fig. 1).[24]

Statistical analysis

IBM SPSS Statistics software (version 28.0.1.0; IBM Corp, Armonk, NY, USA) was utilized for all analyses. The scores from the SEM observations were analyzed using the Kruskal–Wallis test and Mann–Whitney U test with Bonferroni correction. Fleiss' kappa test was applied to assess

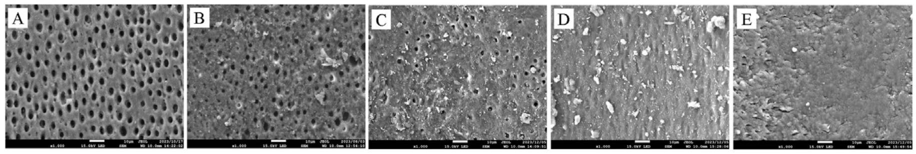

Figure 1 Representative images showing each smear layer score according to Hülsmann et al.[25] (A) Score 1; no smear layer with open dentinal tubules. (B) Score 2; a small amount of smear layer with some occluded dentinal tubules. (C) Score 3; homogenously formed smear layer with only a few open dentinal tubules. (D) Score 4; a homogenous smear layer completely covering the canal wall and occluding dentinal tubules. (E) Score 5; heavy, nonhomogenous smear layer covering the entire canal wall. Bars = 10 μm.

inter- and intra-observer agreements. All analyses were performed at a significance level of $P < 0.05$.

Results

In Experiment 1, the kappa values were 0.86 for interobserver agreement and 0.88 for intraobserver agreement. In Experiment 2, an interobserver kappa value of 0.81 and intraobserver kappa values of 0.89 were obtained.

Experiment 1

Across all canal thirds, the Triton group exhibited significantly lower smear scores compared with the EDTA & NaOCl group, indicating better smear layer removal ($P < 0.05$; Figs. 2 and 3). In the middle and apical thirds of the canal, the SmearOFF group showed significantly lower smear layer scores than the EDTA & NaOCl groups ($P < 0.05$). The Triton and SmearOFF groups demonstrated similar effectiveness in removing the smear layer, with no significant differences ($P > 0.05$).

Experiment 2

When using Triton as the irrigant, both the LAI and SWEEPS groups showed significantly lower smear layer scores compared with the UAI group across all canal thirds ($P < 0.05$; Figs. 4 and 5). The UAI and SI groups showed no significant differences ($P > 0.05$). In the coronal area, all samples in which Triton was activated by LAI demonstrated complete smear layer removal. LAI and SWEEPS demonstrated similar efficiencies in removing the smear layer across all canal thirds, with no significant differences observed ($P > 0.05$).

Discussion

This study evaluated the cleaning efficacies of different dual-action irrigants and various activation techniques for removing the smear layer from root canals. Our findings revealed significant differences in the smear layer scores among different irrigants and various irrigant activation techniques. Therefore, the null hypothesis is rejected.

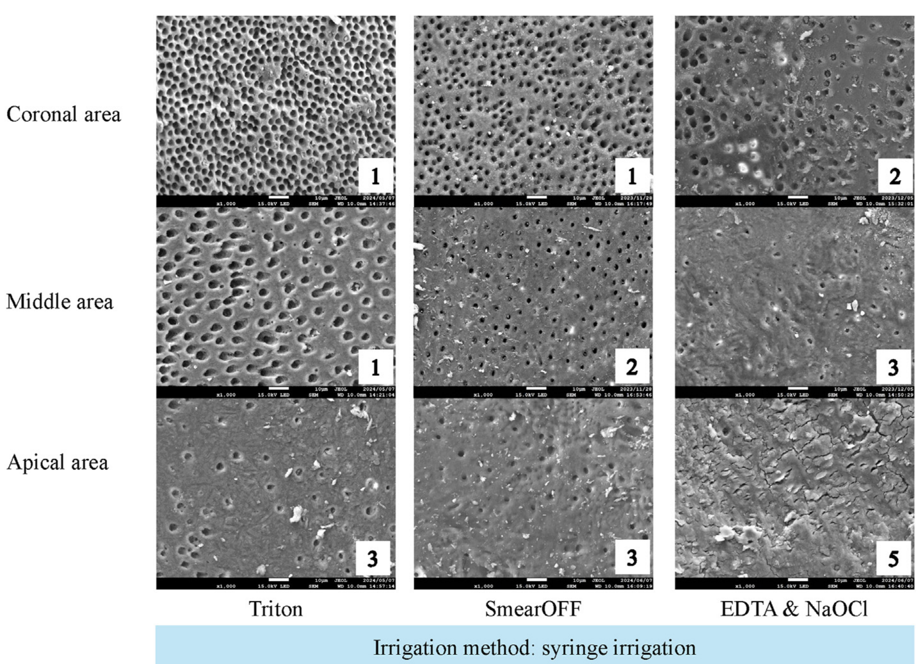

Figure 2 Representative scanning electron microscopy images shown in Experiment 1. Various irrigants were irrigated using syringe irrigation. The scoring criteria are given in the legend of Fig. 1, and the scores are shown in the lower right corner of each panel. Bars = 10 μm. SI, syringe irrigation, EDTA & NaOCl, the combination of ethylenediaminetetraacetic acid and sodium hypochlorite.

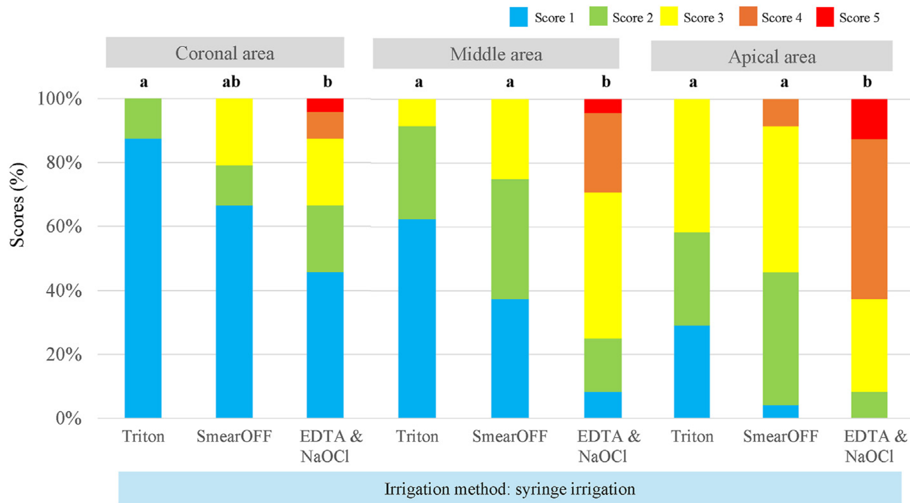

Figure 3 Percentage distribution of the smear layer score in Experiment 1. Various irrigants were applied using syringe irrigation. Different lowercase letters on each bar in an area indicate a significant difference between groups at $P < 0.05$. The scoring criteria are given in the legend of Fig. 1. SI, syringe irrigation; EDTA & NaOCl, the combination of ethylenediaminetetraacetic acid and sodium hypochlorite.

Previous studies have shown the individual performances of the combination of EDTA and NaOCl, SmearOFF, and Triton in removing the smear layer.[25–27] However, no study has compared the efficiency of smear layer removal for the combination of EDTA and NaOCl, SmearOFF, and Triton simultaneously. Similarly, no study has evaluated the smear layer removal efficiency of Triton activated by different techniques such as LAI, SWEEPS, and UAI.

In this study, when the root canals were irrigated with SI, only the EDTA & NaOCl group exhibited either a homogenous or a heavy nonhomogeneous smear layer (score 4 or 5). In contrast, SmearOFF was more effective than this combination in specific areas, while Triton outperformed the combination across all canal thirds. The effectiveness of SmearOFF in removing the smear layer may be due to slightly higher EDTA concentration and the presence of a surfactant,[6] whereas the superiority of Triton is attributed to its combination of citric acid, surfactant, and NaOCl at a high pH.[28,29] Recent studies have also suggested that citric acid can synergize with NaOCl to enhance the effects of smear layer removal.[30,31] Additionally, NaOCl with a high pH, achieved through pH modifiers, demonstrates potent

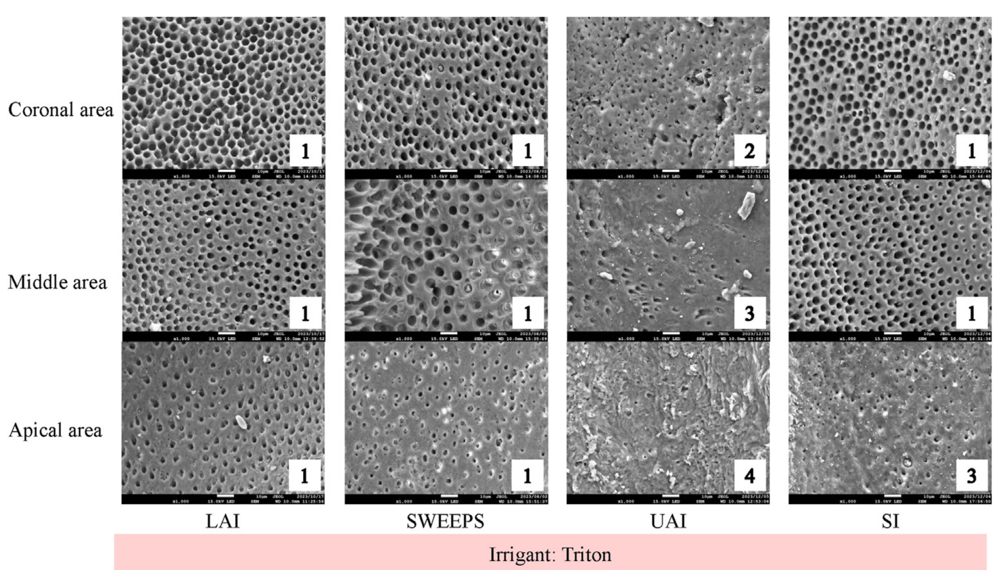

Figure 4 Representative scanning electron microscopy images shown in Experiment 2. Various techniques were used to activate Triton. The scoring criteria are given in the legend of Fig. 1, and the scores are shown in the lower right corner of each panel. Bars = 10 μm. LAI, laser-activated irrigation; SWEEPS, shockwave-enhanced emission photoacoustic streaming; UAI, ultrasonic-activated irrigation; SI, syringe irrigation.

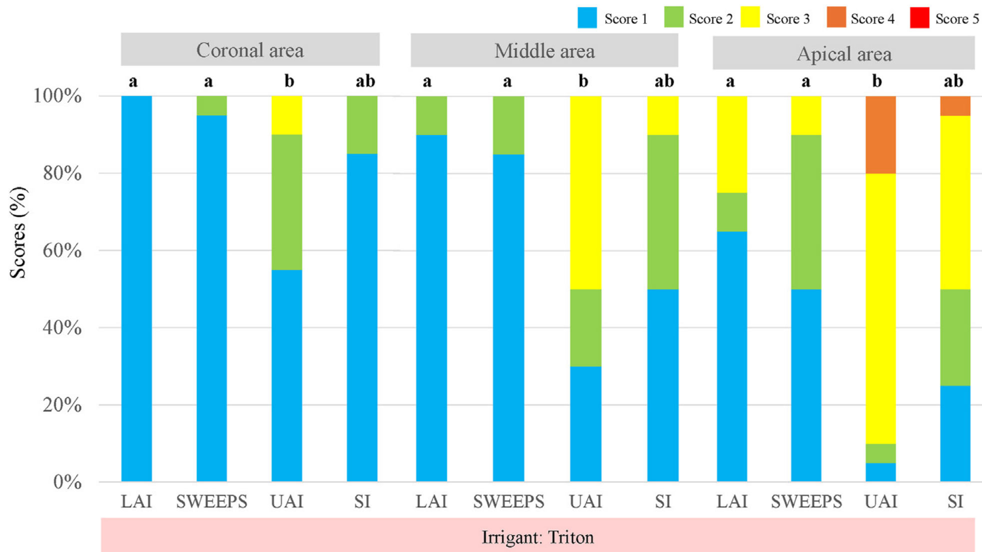

Figure 5 Percentage distribution of the smear layer score in Experiment 2. Various techniques were used to activate Triton. Different lowercase letters on each bar in an area indicate a significant difference between groups at $P < 0.05$. The scoring criteria are given in the legend of Fig. 1. LAI, laser-activated irrigation; SWEEPS, shockwave-enhanced emission photoacoustic streaming; UAI, ultrasonic-activated irrigation; SI, syringe irrigation.

proteolytic activity, enabling it to dissolve necrotic and inflamed tissues that contribute to the formation of the smear layer.[32]

While some studies have demonstrated that Triton is as effective as EDTA in smear layer removal,[33,34] another study reported lower Triton effectiveness of Triton.[29] This discrepancy may be attributed to the differences in the volume of Triton used, the dynamic operation of the cleaning needle, and the duration of root canal irrigation.

Additionally, previous studies have highlighted the limitations of SI, including needle insertion depth, irrigant delivery, and the vapor-lock effect, which can trap air in the apical area and impede complete smear layer removal.[8]

In this study, we evaluated the effects of various irrigant activation techniques, including LAI, SWEEPS, and UAI, to further investigate the efficiency of Triton, particularly in the apical third of the canal. A previous study demonstrated that LAI removed airlocks more effectively than UAI.[9] However, the activation procedures, especially LAI, involved several seconds of activation, followed by similar durations of resting phases across multiple cycles, up to several minutes in total.[21,35] Dual-action irrigants can streamline the activation process, thereby reducing the working time, as seen in the current study, where this time was reduced to 1 min.

In the current study, LAI and SWEEPS activation of Triton resulted in significantly superior smear layer removal across the entire canal area compared with UAI. This result aligns with previous findings on the efficacy of LAI with dual-action irrigants, including Qmix. However, contrary to an earlier study in which UAI with SmearOFF outperformed SI, our results showed similar performance between UAI and SI.[36] The discrepancy may be attributed to the difference in root canal size; the previous study[36] used a root canal preparation size larger than that in this study (#50/0.05 taper). In UAI, smaller-sized preparation may facilitate direct contact between the tip and the root canal wall, especially in the apical third, which may reduce cleaning efficiency.[35,37]

The limitation of the present study is its exclusive focus on the cleaning efficiency of the smear layer without evaluating debris removal. Additionally, although SEM is widely used to observe the cleaning efficiency of root canals, this method does not allow for longitudinal observations. Moreover, the safety implications of cutting or damaging the root canal dentin[38,39] and potential irrigant extrusion outside the root canal foramen due to the settings of the activation techniques[40] have not been addressed.

In conclusion, under the conditions assessed in the current study, Triton removed the smear layer more effectively than the combination of EDTA and NaOCl across all thirds of the root canal. SmearOFF also demonstrated more effective smear layer removal than the combination of EDTA and NaOCl in specific areas. Activating Triton with LAI and SWEEPS enhanced the cleaning efficacy and simplified the root canal irrigation procedures.

Declaration of competing interest

The authors declare no conflict of interest relevant to this study.

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