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Analysis of root surfaces subjected to bioceramic sealer removal methods using scanning electron microscopy following retreatment

David Eduardo Pineda Macas, Soo Nam Jang Jaramillo, Carina Alexandra Stael Muñoz
Faculty of Health Sciences, Universidad Hemisferios Quito, Ecuador, South America
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Abstract
Objective: To evaluate the efficacy of the EDDY, Ultra X, and XP-endo Finisher irrigation activation systems in removing residual bioceramic root canal sealer after endodontic retreatment using scanning electron microscopy (SEM).
Methods: Single-rooted teeth subjected to endodontic retreatment were evaluated and allocated to three groups according to the irrigation activation method: EDDY, Ultra X, and XP-endo Finisher. Following the irrigation protocol, the roots were prepared for SEM evaluation at 2000× magnification. Root canal surfaces were assessed in the apical, middle, and coronal thirds using a five-point ordinal scale to determine the amount of residual material. Two independent and blinded observers performed the evaluations, and the mean score was calculated for each tooth. Differences among activation methods within each root canal third were analyzed using the Kruskal–Wallis test, while differences among root canal thirds within each group were analyzed using the Friedman test. Statistical significance was set at 0.05.
Results: No statistically significant differences were found among EDDY, Ultra X, and XP-endo Finisher in any of the evaluated root canal thirds. In the apical third, the median scores were 3.0 (2.0–5.0), 4.5 (1.5–5.0), and 3.75 (2.0–5.0), respectively (p=0.203); in the middle third, 2.75 (1.0–4.5), 3.0 (2.0–4.5), and 2.75 (1.5–4.5), respectively (p=0.592); and in the coronal third, 2.5 (1.0–4.5), 3.0 (1.0–4.0), and 2.0 (1.0–5.0), respectively (p=0.797). Significant differences among root canal thirds were observed within the Ultra X (p=0.025) and XP-endo Finisher (p=0.005) groups, but not within the EDDY group (p=0.272).
Conclusions: Within the experimental conditions of this study, none of the evaluated irrigation activation methods demonstrated statistically superior efficacy in removing residual bioceramic root canal sealer from the apical, middle, or coronal thirds.

Keywords: Endodontic retreatment, bioceramic root canal sealer, scanning electron microscopy, irrigation activation, EDDY, Ultra X, XP-endo Finisher

Introduction

Effective removal of root filling material during endodontic retreatment is essential to facilitate disinfection of the root canal system and allow subsequent refilling. The use of bioceramic sealers in endodontic practice has increased in recent years because of their biocompatibility, sealing ability, and bioactivity. However, their strong adhesion to dentinal walls may hinder their removal during retreatment and contribute to the persistence of residual material (Zhou *et al*., 2013; Wang *et al*., 2023) [13, 15].

Various irrigation activation systems have been proposed as adjuncts to instrumentation to improve the removal of debris and residual materials from the root canal system. These include sonic and ultrasonic devices, as well as mechanized instruments designed to enhance irrigant contact with areas that may remain inaccessible during conventional instrumentation. The effectiveness of these systems may depend on their design characteristics and their ability to induce irrigant movement and mechanically disrupt residual material adhered to the canal walls.

The XP-endo Finisher (FKG, La Chaux-de-Fonds, Switzerland) is a nickel-titanium instrument with a #30 tip size and zero taper, manufactured from a shape-memory alloy that allows it to alter its configuration during rotation. Its ability to expand within the root canal promotes contact with the canal walls and irrigant agitation, which has demonstrated potential for reducing residual root filling material after retreatment (Dos Santos *et al*., 2022; Matoso *et al*., 2022) [4, 11].

Among ultrasonic systems, Ultra X (Eighteeth, Changzhou, China) operates at a frequency of 45 kHz and produces acoustic streaming, agitation, and cavitation within the irrigant. These phenomena may enhance the interaction between the irrigating solution and the canal walls and contribute to the removal of residual material from areas that are difficult to access (Güven *et al*., 2022). Recent studies have investigated its potential to facilitate the removal of root filling materials during endodontic retreatment (Cıkrık & İnce Yusufoğlu, 2025) [2].

EDDY (VDW, Munich, Germany) is a sonic activation system that uses a flexible polyamide tip and operates at a frequency of approximately 6000 Hz. Its three-dimensional oscillatory motion promotes irrigant agitation and the generation of hydrodynamic phenomena, including cavitation and acoustic streaming. These characteristics have supported its use as an adjunctive method to improve the removal of residual materials during retreatment procedures (Donnermeyer *et al*., 2019 [3]; Cıkrık & İnce Yusufoğlu, 2025) [2].

The amount of residual material following retreatment can be assessed using different imaging techniques. Scanning electron microscopy (SEM) allows detailed evaluation of dentinal surfaces and has been used to assess the presence of residual endodontic materials after instrumentation and irrigation procedures (Grandini *et al*., 2005; Andonov *et al*.,

2022; Zaniboni *et al*., 2021) [1, 7, 14]. Its high resolution enables the identification and comparison of residual material in different regions of the root canal.

Despite the availability of different irrigation activation systems, evidence regarding their relative effectiveness in removing bioceramic sealers during retreatment remains limited, particularly when sonic, ultrasonic, and mechanized systems are compared using a standardized assessment of the different root canal thirds. Therefore, determining whether differences exist in the amount of residual bioceramic sealer following the use of different irrigation activation methods is clinically and scientifically relevant.

Therefore, the aim of this study was to evaluate the effectiveness of EDDY, Ultra X, and XP-endo Finisher in removing residual bioceramic sealer after endodontic retreatment by assessing the apical, middle, and coronal thirds using SEM. The null hypothesis was that there would be no differences in the amount of residual sealer among the three activation methods in any of the evaluated root canal thirds

Materials And Methods

Study Design and Sample Selection

An experimental *in vitro* study was conducted using 60 human single-rooted teeth extracted for orthodontic or periodontal reasons. The specimens were randomly allocated to three experimental groups (n = 20) according to the irrigation activation method used for the additional removal of bioceramic sealer.

The teeth were stored in sterile saline solution for seven days until processing. The inclusion criteria were single-rooted teeth with mature apices, no root curvature greater than 20°, and no resorption or calcification. Teeth with extensive restorations compromising structural integrity, calcifications, perforations, internal or external resorption, or previous endodontic treatment were excluded.

Specimen Preparation

The crowns were sectioned using a diamond disc to standardize the root length to 13 ± 1 mm. Biomechanical preparation was performed using the Reciproc Blue R25 reciprocating system (25/.08), with movements of 150° counterclockwise and 30° clockwise. During instrumentation, the root canals were irrigated with 2 mL of 5.25% sodium hypochlorite (NaOCl) between instruments. Final irrigation consisted of 5 mL of 5.25% NaOCl, 2 mL of 17% EDTA, and 5 mL of distilled water.

Root Canal Filling

The root canals were filled using a single-cone technique with Reciproc Blue R25 gutta-percha cones and the bioceramic sealer MTA Fillapex (Angelus, Londrina, Brazil). The coronal access was sealed with Cavit-G (3M ESPE, Germany). The specimens were stored at 37°C and 100% humidity for 14 days to allow the sealer to set.

Endodontic Retreatment and Activation Protocols

Retreatment was performed using the Reciproc Blue R40 reciprocating system (40/.06), with movements of 150° clockwise and 30° counterclockwise. After initial removal of the root filling material, the specimens were randomly allocated to three groups (n = 20) according to the activation method used.

XP-endo Finisher group: The XP-endo Finisher instrument was used at 800 rpm and 1 N·cm. The 5.25% NaOCl irrigant was activated for three 30-s cycles. Subsequently, final irrigation was performed with 2 mL of 17% EDTA followed by 5 mL of physiological saline solution.

EDDY group: The EDDY sonic activation system (VDW, Munich, Germany) was used with a flexible polyamide tip (25/.04) activated at a frequency of 6000 Hz. The 5.25% NaOCl was activated for three 30-s cycles. Subsequently, final irrigation was performed with 2 mL of 17% EDTA followed by 5 mL of physiological saline solution.

Ultra X group: The Ultra X ultrasonic device (Eighteeth, Changzhou, China) was used with a 20/.02 metallic tip activated at 45 kHz at maximum power. The tip was positioned 2 mm short of the working length. The 5.25% NaOCl was activated for three 30-s cycles. Subsequently, final irrigation was performed with 2 mL of 17% EDTA followed by 5 mL of physiological saline solution.

Scanning Electron Microscopy Preparation and Evaluation

Following the retreatment and activation procedures, the roots were longitudinally sectioned using a controlled fracture technique. Initially, a superficial longitudinal cut was made with a diamond disc without penetrating or contacting the root canal to establish a fracture line. Additionally, superficial cuts approximately 2–3 mm in length were made in the coronal and apical regions of the root to weaken these areas without reaching the root canal. Subsequently, a cement spatula was inserted into the cut line, and controlled pressure was applied until the longitudinal fracture was completed.

The selected root halves were gold-coated by sputter coating and mounted on metal stubs for scanning electron microscopy (SEM) evaluation. Images of the coronal, middle, and apical thirds were obtained at 2000× magnification with an accelerating voltage of 10 kV.

The amount of residual material on the dentinal walls was evaluated using a five-point ordinal scale based on the criteria described by Drukteinis and Balciuniene (2006) [5]: score 1, 0–25% residual material coverage; score 2, 26–50%; score 3, 51–75%; score 4, 76–99%; and score 5, 100% coverage, corresponding to no removal.

The micrographs were coded by an independent investigator who was not involved in their evaluation. Subsequently, two previously calibrated examiners, blinded to the experimental groups, independently evaluated the images using the five-point ordinal scale. For each tooth and root canal third, the mean score assigned by the two examiners was calculated.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics, version 29.0 (IBM Corp., Armonk, NY, USA). Due to the ordinal nature of the scores obtained by scanning electron microscopy, nonparametric tests were used.

The scores independently assigned by the two blinded examiners were averaged for each tooth and root canal third, and the resulting values were used for statistical analysis. Data were expressed as median and minimum–maximum values. The Kruskal–Wallis test was used to compare the three irrigation activation methods (EDDY, Ultra X, and XP-endo Finisher) within each root canal third. The

Friedman test was used to compare scores among the three root canal thirds within each activation method, as these measurements were obtained from the same teeth. A significance level of $\alpha = 0.05$ was established, and p values < 0.05 were considered statistically significant.

Results

No statistically significant differences were observed in the amount of residual bioceramic sealer among EDDY, Ultra X, and XP-endo Finisher in any of the evaluated root canal thirds.

Table 1: Comparison of Bioceramic Sealer Removal Scores among Irrigation Activation Methods According to Root Canal Thir

Root canal third	EDDY	Ultra X	XP-endo Finisher	Kruskal–Wallis p-value
Apical	3.0 (2.0–5.0)	4.5 (1.5–5.0)	3.75 (2.0–5.0)	0.203
Middle	2.75 (1.0–4.5)	3.0 (2.0–4.5)	2.75 (1.5–4.5)	0.592
Coronal	2.5 (1.0–4.5)	3.0 (1.0–4.0)	2.0 (1.0–5.0)	0.797

Source: Prepared by the authors from the analyzed tomographic database.

*Data are expressed as median (minimum–maximum). p-values were obtained using the Kruskal–Wallis test.

When comparing scores among the three root canal thirds within each activation method, statistically significant differences were observed in the Ultra X ($p = 0.025$) and XP-endo Finisher ($p = 0.005$) groups, whereas no statistically significant differences among root canal thirds were found in the EDDY group ($p = 0.272$).

Table 2: Comparison of Bioceramic Sealer Removal Scores among Root Canal Thirds within Each Irrigation Activation Method

Activation method	Apical	Middle	Coronal	*p*-value
EDDY	3.0 (2.0–5.0)	2.75 (1.0–4.5)	2.5 (1.0–4.5)	0.272
Ultra X	4.5 (1.5–5.0)	3.0 (2.0–4.5)	3.0 (1.0–4.0)	0.025
XP-endo Finisher	3.75 (2.0–5.0)	2.75 (1.5–4.5)	2.0 (1.0–5.0)	0.005

Source: Prepared by the authors from the analyzed tomographic database.

*Data are expressed as median (minimum–maximum). p-values were obtained using the Friedman test.

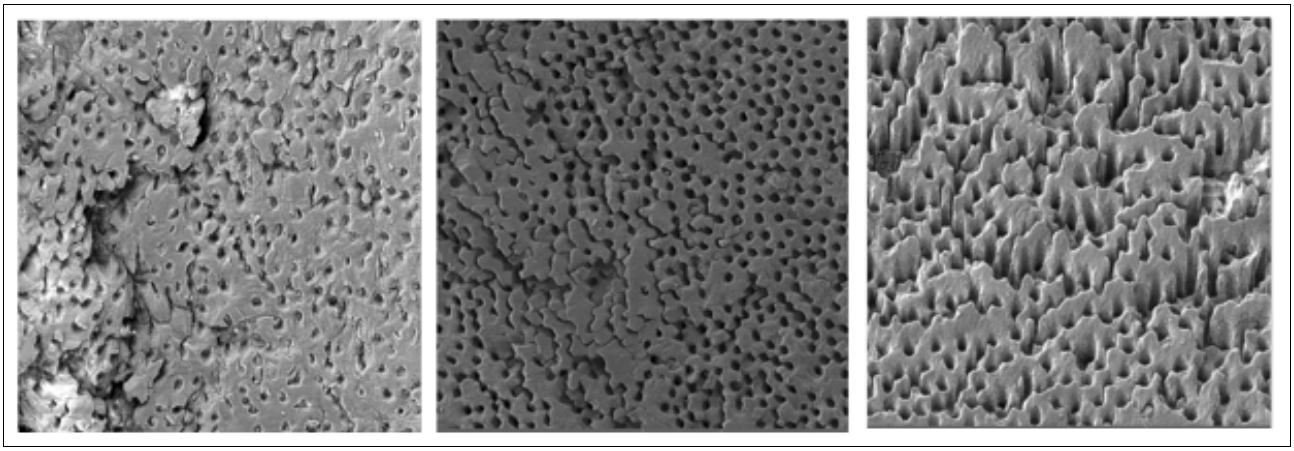

Fig 1: Representative scanning electron microscopy images (×2000) of the coronal, middle, and apical thirds after treatment with the EDDY activation method

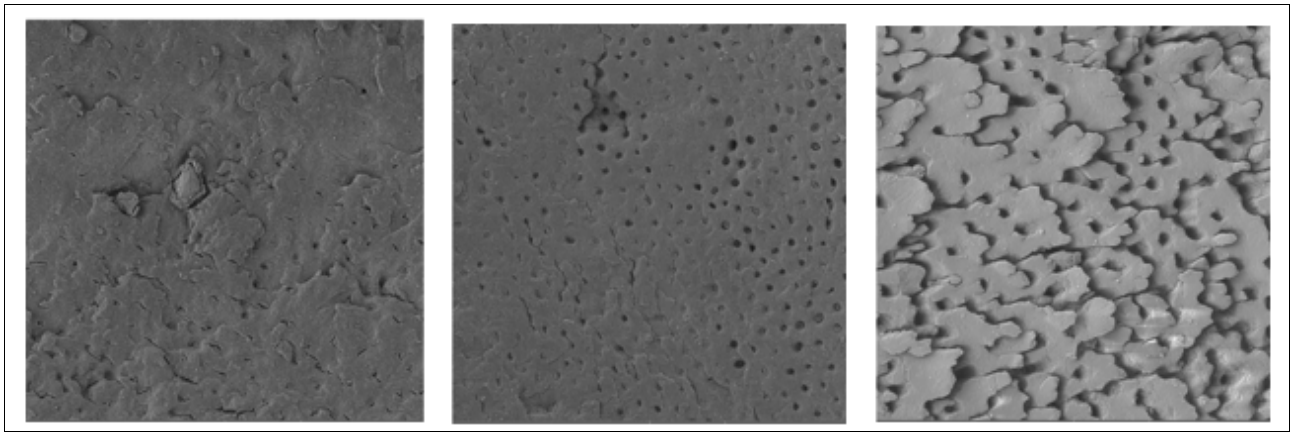

Fig 2: Representative scanning electron microscopy images (×2000) of the coronal, middle, and apical thirds after treatment with the Ultra X activation method

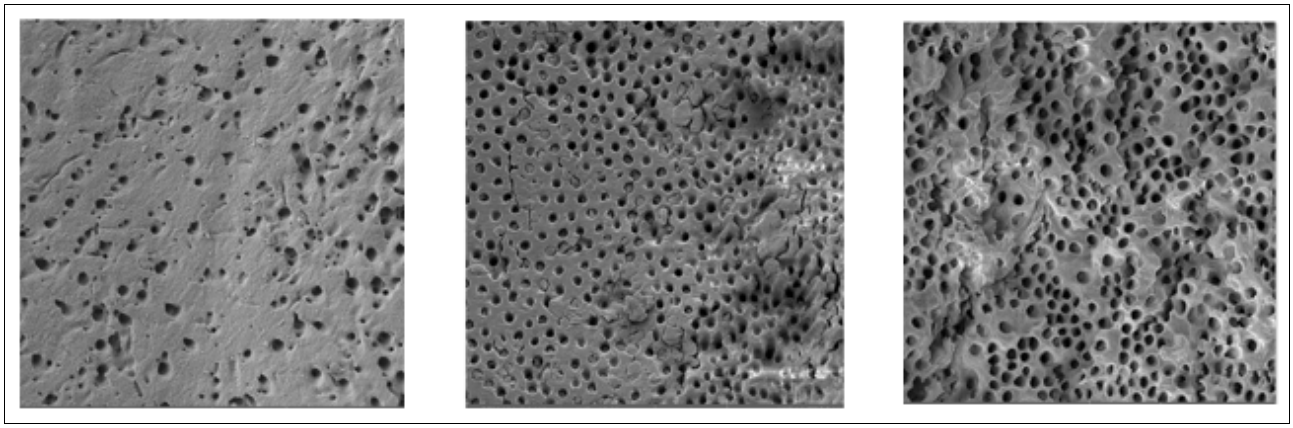

Fig 3: Representative scanning electron microscopy images (×2000) of the coronal, middle, and apical thirds after treatment with the XP-endo Finisher activation method.

Discussion

The aim of the present study was to evaluate the effectiveness of the EDDY, Ultra X, and XP-endo Finisher irrigation activation systems in removing residual bioceramic sealer after endodontic retreatment using scanning electron microscopy. The results showed no statistically significant differences among the three systems in any of the evaluated root canal thirds. In the apical, middle, and coronal thirds, p-values of 0.203, 0.592, and 0.797, respectively, were obtained. Therefore, under the experimental conditions of the present study, no statistically significant difference in the amount of residual bioceramic sealer was demonstrated among the evaluated activation systems.

Complete removal of root filling material during retreatment remains a challenge because of the interaction among root canal anatomy, the characteristics of the residual material, and the removal protocol employed. Gomes *et al.* (2017) [6] reported that no retreatment technique can completely clean the root canal walls throughout their entire extent, although the use of ultrasonic irrigation may enhance the removal of residual material. Similarly, Kim *et al.* (2015) [10] observed the persistence of residual material by scanning electron microscopy after retreatment of root canals filled with different materials, including a calcium silicate-based sealer and AH Plus. These findings are consistent with those of the present study, in which residual material was also observed regardless of the activation system employed.

The results of the present study partially differ from those reported by Cıkrık and Yusufoğlu (2025) [2], who evaluated the effectiveness of EDDY and Ultra X in removing MTA Fillapex and BioSerra using SEM. In specimens filled with MTA Fillapex, EDDY performed better than conventional irrigation in all three root canal thirds; however, the differences between EDDY and Ultra X were not statistically significant in all thirds. In contrast, the present study found no statistically significant differences among EDDY, Ultra X, and XP-endo Finisher in any of the evaluated thirds. This discrepancy may be related to methodological differences between the two studies, including the experimental group design, retreatment protocol, instrumentation systems, irrigant concentrations and volumes, and the inclusion of XP-endo Finisher as an additional removal method in the present study. Therefore, although both studies used MTA Fillapex and SEM, their findings should be interpreted in light of the differences between their experimental protocols.

The three systems evaluated in the present study have different mechanisms of action. EDDY uses a flexible polyamide tip that generates three-dimensional irrigant movement through sonic activation, whereas Ultra X uses ultrasonic energy to induce acoustic movement of the irrigant. XP-endo Finisher, in turn, is a mechanized instrument designed to enhance contact with irregularities and difficult-to-access areas within the root canal. However, these differences in mechanism did not translate into a statistically significant advantage for any of the systems in the present study.

The findings are consistent with previous research demonstrating that activation systems may improve the removal of certain materials but do not guarantee complete cleaning. Donnermeyer *et al.* (2019) [3] evaluated EDDY, passive ultrasonic irrigation, and XP-endo Finisher for the removal of calcium hydroxide from artificial irregularities and observed differences among some methods, particularly in the apical region, although none of the systems completely removed the material. These findings support the concept that irrigant activation may contribute to the removal of residual material, but its effectiveness may depend on the material being removed and the experimental conditions.

The intragroup analysis showed statistically significant differences among root canal thirds in the Ultra X (p = 0.025) and XP-endo Finisher (p = 0.005) groups, whereas no statistically significant differences were observed in the EDDY group (p = 0.272). These findings indicate that the amount of residual material did not exhibit a uniform distribution along the root canal for all evaluated systems. Root canal anatomy and the conditions affecting irrigant access and circulation may contribute to these variations. The apical third represents a particularly complex region because of its reduced dimensions and the difficulties associated with irrigant exchange. Gomes *et al.* (2017) [6] identified this region as critical for residual material removal, whereas Versiani *et al.* (2013) [12] demonstrated by micro-computed tomography that certain anatomical configurations may result in areas of the root canal walls that are not directly contacted by instruments, favoring the persistence of residual material.

The persistence of residual sealer may also be related to the properties of the material used for root canal filling. Kim *et al.* (2015) [10] demonstrated that residual sealer may remain on the root canal walls and in specific dentinal regions after retreatment. Likewise, Huffman *et al.* (2009) [9] observed

high displacement resistance of ProRoot Endo Sealer and described phenomena associated with the formation of calcium phosphate and apatite phases. These processes may help explain the difficulty in completely removing certain sealers once they have interacted with dentin. Therefore, the presence of residual material observed in the present study should not be attributed solely to the characteristics of the activation systems but may also be influenced by the interaction between the sealer and the dentinal surface.

Scanning electron microscopy allowed detailed evaluation of the root surfaces and standardized comparison of residual material among the experimental groups. The use of a five-point ordinal scale, together with independent and blinded assessment by two previously calibrated examiners, helped standardize the evaluation of the micrographs and reduce the risk of observer bias. The mean of the scores assigned by both examiners was used as the final value for each tooth and root canal third.

Overall, although numerical differences were observed among the group medians, these differences did not reach statistical significance. Therefore, the results do not support the superiority of EDDY, Ultra X, or XP-endo Finisher over the other systems for the removal of bioceramic sealer under the conditions evaluated. The differences observed compared with previous studies may be related to variations in the experimental protocol, instrumentation system, activation parameters, irrigant, and method used to assess residual material.

The findings suggest that none of the evaluated activation systems alone guarantees complete removal of bioceramic sealer during retreatment. Irrigation activation should be considered a complementary component of a protocol that includes adequate mechanical removal, chemical irrigation, and consideration of the anatomical characteristics of the root canal system. Under the experimental conditions of the present study, EDDY, Ultra X, and XP-endo Finisher exhibited statistically comparable performance, although differences in the distribution of residual material among root canal thirds were observed within the Ultra X and XP-endo Finisher groups.

Conclusions

Under the experimental conditions of this study, no statistically significant differences were found among EDDY, Ultra X, and XP-endo Finisher in the removal of residual bioceramic sealer from the apical, middle, and coronal thirds of the root canal. Although numerical differences were observed among the methods, none reached statistical significance; therefore, no superiority of any of the evaluated systems was demonstrated.

The intragroup analysis revealed statistically significant differences in the distribution of scores among root canal thirds for Ultra X and XP-endo Finisher, whereas EDDY showed no statistically significant differences among these regions. These findings suggest that the distribution of residual material may vary according to root canal location and the activation system employed.

Overall, EDDY, Ultra X, and XP-endo Finisher demonstrated statistically comparable effectiveness in removing bioceramic sealer under the experimental conditions evaluated. The persistence of residual material observed in the specimens highlights that complete sealer removal remains a challenge during endodontic retreatment.

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