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Efficacy of solvent-free retreatment files with different flute designs in removing aged bioceramic sealer: A micro-CT study Purpose

Ahmed A. Alelyani[1*]

[1]Department of Restorative Dentistry-Division of Endodontics, College of Dentistry, Najran University, Najran, Saudi Arabia

*Corresponding author: Ahmed A. Alelyani, Department of Restorative Dentistry-Division of Endodontics, College of Dentistry, Najran University, Najran, Saudi Arabia, e-mail address: emal89@yahoo.com

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This study aimed to compare the efficacy of four contemporary retreatment file systems, i.e., R-Endo, XP-Endo Retreatment, HyFlex Remover, and MicroMega Remover, in the solvent-free removal of aged bioceramic sealers from root canals, and to elucidate the relationship between file design and retreatment performance using advanced micro-computed tomography (micro-CT).

Methods

Forty extracted human mandibular premolars with single straight canals were prepared and obturated using either Total Fill BC or BioRoot RCS sealers, then aged for one year. Specimens were randomly assigned to four retreatment file systems (n = 5 per subgroup), and retreatment was performed without solvents according to manufacturers' protocols. Residual filling material was quantified pre- and post-retreatment using micro-CT. Data were analyzed with repeated-measures analysis of variance.

Results

XP-Endo Retreatment and HyFlex Remover showed superior removal efficiency, particularly in middle and cervical thirds (>84%), whereas R-Endo consistently exhibited the lowest performance, especially apically. MicroMega Remover demonstrated intermediate efficacy, outperforming R-Endo but less effective than XP-Endo Retreatment and HyFlex. No significant differences were observed between Total Fill BC and BioRoot RCS sealers. Results indicated significant effects of canal third and file system ($p < 0.001$) and a significant canal third × file system × sealer interaction ($p = 0.037$).

Conclusions

File design and metallurgical properties significantly influence the mechanical retrievability of aged calcium silicate–based sealers in solvent-free retreatment. XP-Endo Retreatment and HyFlex Remover provided superior cleaning under *in vitro* conditions. These findings inform clinicians on the selection of retreatment instruments for predictable removal of bioceramic sealers.

Keywords:

Endodontic retreatment; bioceramic sealer; Micro-CT; XP-Endo Retreatment; HyFlex Remover; Remover; R-Endo.

Introduction

The successful treatment of endodontic infections relies heavily on effective root canal sealing, which is achieved through the application of bioceramic sealers [15]. These sealers have gained popularity due to their biocompatibility, excellent sealing properties, and ability to promote healing [24]. However, these same properties may pose significant challenges during retreatment, as bioceramic sealers are known for strong adhesion and deep penetration into dentinal tubules, potentially hampering their complete removal [4, 23]. The removal of aged bioceramic sealers during endodontic retreatment is critical to ensure the success of subsequent treatment procedures [2].

Traditionally, a combination of manual instrumentation, rotary files, and chemical solvents such as chloroform or xylene has been employed to facilitate the removal of gutta-percha and sealer residues [1, 10]. While solvents can aid in softening obturating materials, they may also modify the viscosity and adherence of bioceramic sealers~~, potentially increasing the difficulty of their removal and resulting in residual material adhering to canal walls~~ [15]. Furthermore, recent studies have questioned the necessity and benefits of solvents, especially when advanced mechanical retreatment systems are available [9, 19]. Consequently, solvent-free retreatment protocols have garnered increased clinical interest for promoting more predictable, efficient, and safer procedures [19, 20].

A variety of nickel–titanium (NiTi) retreatment file systems have been developed to address this challenge, each incorporating distinct design philosophies in terms of flute geometry, cross-sectional shape, and tip configuration [15]. These flute designs play a critical role in cutting efficiency, debris removal, canal centering, and adaptation to canal anatomy [14, 22]. Among them, rectangular, triangular, S-shaped, and expanding-core designs have demonstrated varying levels of effectiveness. While some files operate in continuous rotary motion, others use reciprocation or adaptive motion to enhance canal shaping, cleaning and reducing stress on instruments [18]. However, it remains unclear whether the flute geometry itself—independent of the motion kinematics—can significantly influence the retreatment outcome, particularly in solvent-free protocols.

Several *in vitro* studies have compared retreatment file systems [5, 11, 13], but few have directly addressed the impact of flute design on the mechanical removal of aged

bioceramic sealers in the absence of solvents. Moreover, most available data focus on volume reduction alone, without evaluating residual material distribution within different canal thirds or accounting for the challenges posed by complex sealer-dentin bonding. There is a clear need to investigate how specific flute geometries interact with canal walls and influence removal efficacy under standardized solvent-free conditions.

Therefore, the present study aimed to compare the efficacy of four retreatment file systems, each featuring distinct flute designs, in the removal of two aged bioceramic sealers from root canals. This study utilized advanced micro-CT imaging and established residual scoring methods to quantitatively and qualitatively assess the amount of remaining material after the retreatment process. By elucidating the relationship between flute design and retreatment performance, this research seeks to inform clinical best practices, enhance the predictability of endodontic retreatment outcomes, and contribute to the broader field of material–instrument interaction in root canal therapy. It was hypothesized that the flute design of retreatment file systems would not significantly influence the removal efficacy of aged bioceramic sealers under solvent-free conditions.

Materials and methods

The manuscript of this laboratory study was written in accordance with the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines.

Specimen selection and preparation

This prospective comparative investigation utilized forty extracted human mandibular premolar teeth. Specimens were selected according to the following inclusion criteria: radiographically confirmed single root canals with fully formed apices, absence of caries on the crown or root structure, root canals exhibiting curvature less than 10 degrees, and no history of endodontic intervention. Straight canals (<10°) were specifically chosen to minimize anatomical variability and ensure standardization across specimens. Because canal curvature can influence instrument stress, shaping ability, and debris removal, restricting the sample to straight canals allowed the study to isolate and evaluate the effect of flute design on sealer removal under controlled conditions.

The teeth were extracted for orthodontic reasons, and informed consent was obtained from all patients for the use of their extracted teeth in experimental procedures. Following extraction, the specimens were decontaminated via immersion in a 0.1% thymol solution for one week.

All residual external soft tissue and calculus deposits were meticulously removed through mechanical debridement. To standardize root length, crowns were sectioned perpendicularly to the long axis using a diamond disc (IsoMet 1000; Buehler, USA) operating at 1000 revolutions per minute (rpm), resulting in uniform root segments measuring 12 mm from the anatomical apex to the coronal reference plane. Standard endodontic access cavities were prepared. Working length (WL) was determined by inserting a size 10 K-file (ISO standard) into the canal until its tip was visualized 1 mm coronal to the apical foramen.

Root canal instrumentation and obturation

Canal preparation was performed with ProTaper Universal rotary instruments (Dentsply Maillefer, Switzerland) according to the manufacturer's recommended sequence, culminating in instrumentation to size F3 (tip size 30, taper 0.09). Irrigation with 2 mL of 2.5% sodium hypochlorite (NaOCl; Sigma-Aldrich, USA) was administered between each instrument change via a 27-gauge side-vented needle (Eoskyo, China). A final irrigation regimen employed 1 mL of 17% ethylenediaminetetraacetic acid (EDTA; Sigma-Aldrich, USA) to eliminate the smear layer. Canals were subsequently irrigated with 2 mL of normal saline solution and dried using sterile paper points (Meta Biomed, Korea).

Following instrumentation, the forty specimens were randomly divided into two equal groups (n = 20 per group) according to the bioactive sealer used during obturation: Sealer A – Total Fill BC sealer (FKG Dentaire, La Chaux-desFonds, Switzerland) and Sealer B – BioRoot RCS (Septodont, Saint Maur Des Fosses, France). Randomization was performed using a simple randomization method with a random number table to ensure unbiased group allocation. Obturation was performed using a single-cone technique with size 40/0.04 gutta-percha cones (Meta Biomed Co., Ltd., Cheongju, South Korea) and the allocated sealer (0.05 mL), introduced 1 mm short of the working length with a #30 Lentulo spiral (Dentsply Maillefer, Ballaigues, Switzerland) to ensure uniform coating of

the canal walls. employing a gentle reciprocal motion for 5 seconds to ensure uniform canal wall coverage. The master cone was seated to the established WL and vertically compacted. Superfluous gutta-percha was removed using a heated excavator, and access cavities were sealed with Fuji II LC capsule resin-modified glass ionomer restorative material (GC Corporation, Tokyo, Japan). All obturated specimens were incubated at 37°C under 100% relative humidity for 1 year to facilitate complete sealer setting and simulate long-term intraoral aging conditions.

Retreatment procedure

After 1 year aging period, retreatment was performed. The access cavity was unsealed with a round high-speed diamond bur. Each sealer group (n = 20) was subdivided into four subgroups (n = 5 per subgroup) according to the retreatment file system used. During retreatment, no solvent was used. The file systems used to remove aged root canal filling were: R-Endo Remover (Micro-Mega, France) served as the control group, XP-endo Retreatment System (FKG Dentaire, Switzerland), HyFlex Remover (Coltene/Whaledent, Switzerland) and Remover (Micro-Mega, France).

For the R-Endo Remover group, the R1, R2, and R3 files were used in a crown-down sequence for coronal, middle, and apical thirds, respectively, at 350 rpm and 1.5 N·cm torque. In the XP-endo Retreatment group, filling material removal was performed using the DR1, DR2, and DR3 files for the coronal, middle, and apical thirds, respectively. The files were operated at 800–1000 rpm with a torque of 1 N·cm. In the HyFlex Remover group, a single NiTi rotary instrument specifically designed for retreatment with an ISO size 30 tip and variable 7% taper was used. It was operated at 400 rpm and 2.5 N·cm torque in a crown-down motion, applying light apical pressure and brushing strokes against the canal walls until the working length was reached. For the Remover group with a single file system, the file was used at 600 rpm and 1.5 N·cm torque.

Irrigation with 2 mL of 2.5% sodium hypochlorite was performed intermittently—no more than three times per file system—to facilitate the flushing of loosened debris during instrumentation. A 27-gauge side-vented needle (Eoskyo, Guangzhou, China) was used for irrigation. All instruments were operated strictly under the respective manufacturers' instructions. Instruments were discarded after use in five canals to maintain efficiency.

Retreatment was considered complete when the working length was achieved, canal walls appeared free of visible filling remnants, and no obturation material was observed on the final instrument used. A final rinse with 2 mL of 2.5% sodium hypochlorite concluded the procedure.

Micro-computed tomography (Micro-CT) evaluation

Specimens underwent micro-CT scanning (SkyScan 1173, Bruker-microCT, Belgium) after obturation and following retreatment procedures. Scan parameters included: 9 µm isotropic voxel resolution, 80 kV source voltage, 100 µA current, 500 ms exposure time, and a 1.0 mm aluminum filter to mitigate beam hardening artifacts. Data acquisition involved a 360° rotation with a 0.4° rotation step. Image reconstruction was executed using NRecon software (v1.6.4, Bruker-microCT).

Quantification of residual filling material volume was performed using CTAn software (v1.16, Bruker-microCT). A region of interest (ROI) encompassing the entire root canal space was defined. Segmentation of the filling material was achieved through grey-scale thresholding. The percentage volume of residual filling material was calculated by comparing volumetric data derived from pre- and post-retreatment scans. Three-dimensional visualization of the segmented structures was rendered using CTvol software (Bruker-microCT). A single experienced examiner, who was blinded to the experimental groups to reduce evaluation bias, performed all micro-CT analyses.

Statistical analysis

Statistical analyses were conducted using SPSS Statistics software (version 28.0, IBM Corp., USA). The normality of removal efficiency at apical, middle, cervical thirds was assessed with the Shapiro–Wilk test, confirming a normal distribution ($p > 0.05$). A repeated-measures analysis of variance (RM-ANOVA) was employed to evaluate within-subject effects of canal third and its interactions with file system and sealer type. Between-subject effects were used to assess the main and interaction effects of file system and sealer on overall removal efficiency. Where significant main effects were detected ($p < 0.05$), post-hoc pairwise comparisons were performed using Tukey's multiple comparison test. Statistical significance was set at $\alpha = 0.05$ for all analyses, and effect sizes were reported as partial eta squared (η^2).

Results

Table 1 presents the mean ± standard deviation percentage of filling material removed from the apical, middle, and cervical thirds of root canals for each retreatment file system and sealer type. Across both sealers, the XP-Endo and HyFlex Remover systems generally achieved the highest removal values in all canal thirds, with especially high means in the middle and cervical regions (>84%). The R-Endo system consistently showed the lowest removal efficiency, particularly in the apical third. The MicroMega Remover performed better than R-Endo in most thirds but was generally less effective than XP-Endo and HyFlex. Patterns of removal were similar for Total Fill BC and BioRoot RCS sealers, with middle thirds showing the highest mean removal and apical thirds the lowest across all instrument types.

Table 1: Mean ± standard deviation percentage of root canal filling material removed from the apical, middle, and cervical thirds for each retreatment file system and sealer type.

Sealer	File system	Apical (Mean ± SD)	Middle (Mean ± SD	Cervical (Mean ± SD)
Total Fill BC	R-Endo	56.24 ± 10.85	75.56 ± 8.14$_{b}$	79.50 ± 6.31$_{d,e}$
	XP-Endo Retreatment	79.69 ± 6.87$_{a}$	93.40 ± 4.01$_{c}$	87.95 ± 5.38$_{d,f}$
	HyFlex Remover	79.77 ± 10.47$_{a}$	94.26 ± 2.73$_{c}$	89.30 ± 7.02$_{f}$
	Remover	67.78 ± 4.27	81.37 ± 4.01$_{b}$	77.89 ± 7.37$_{e}$
BioRoot RCS	R-Endo	53.37 ± 5.65	76.24 ± 4.23$_{d}$	81.27 ± 9.35$_{g,h}$
	XP-Endo Retreatment	78.01 ± 4.89$_{a,b}$	92.62 ± 3.89	86.68 ± 7.22$_{g,i}$
	HyFlex Remover	74.43 ± 6.92$_{a,c}$	84.59 ± 6.25$_{e}$	93.99 ± 4.13$_{i}$
	Remover	71.05 ± 8.38$_{b,c}$	80.63 ± 3.27$_{d,e}$	72.14 ± 6.71$_{h}$

Table 2 presents the Tests of within-subject effects from the RM-ANOVA. RM-ANOVA showed a significant main effect of canal third, $F(2,112) = 101.06$, $p < .001$, partial $\eta^2 = .64$, indicating material removal efficiency differed among apical, middle, and cervical thirds. There was also a significant canal third × file system interaction, $F(6,112) = 7.89$, $p < .001$, partial $\eta^2 = .30$, demonstrating that the removal pattern across canal thirds varied by instrument type. The canal third × sealer interaction was not significant ($p = .556$), suggesting sealer type did not alter the removal pattern across thirds. However, the three-way interaction of canal third × file system × sealer was significant, $F(6,112) = 2.33$,

p = .037, partial η^2 = .11, indicating that the differences among thirds depended on the combination of file system and sealer.

Table 2: Results of RM-ANOVA for within-subjects effects assessing the influence of canal third (apical, middle, cervical), retreatment file system, and sealer type on percentage of filling material removal.

Effect	**df (factor, error)**	**F**	**p-value**	**Partial η^2**
Canal third	2, 112	101.06	<.001	.64
Canal third × File system	6, 112	7.89	<.001	.30
Canal third × Sealer	2, 112	0.59	.556	.01
Canal third × File system × Sealer	6, 112	2.33	.037	.10

Table 3 presents the results of the between-subjects analysis from the RM-ANOVA, examining the overall differences in removal efficiency between four retreatment file systems and the two sealer types. A highly significant main effect of file system was observed, $F(3, 56) = 71.11$, $p < .001$, partial $\eta^2 = .79$, indicating large differences in mean removal performance among the instruments. In contrast, the main effect of sealer type was not significant, $F(1, 56) = 2.40$, $p = .127$, suggesting no meaningful difference in overall removal efficiency between Total Fill BC and BioRoot RCS. The interaction between file system and sealer was also non-significant, $F(3, 56) = 0.54$, $p = .658$, indicating that the relative ranking of file systems did not depend on the sealer used.

Table 3: Tests of between-subjects effects from the RM-ANOVA comparing overall removal efficiency between four file systems and two bioceramic sealers.

Effect	df	F	p-value	Partial η^2
File system	3, 56	71.11	<.001	.79
Sealer	1, 56	2.40	.127	.04
File system × Sealer	3, 56	0.54	.658	.03

Figure 1 demonstrates a representative specimen of Total Fill BC sealer group filled with gutta-percha. Before retreatment (A–D), the canal space in all views and cross-sections appears uniformly filled (Fig. 1E). After retreatment (F–J) with R-Endo file system, a reduction in the filled area is evident in all thirds, particularly in the apical third. However, a residual material adherent to the canal walls was prominent at the cervical and middle thirds, and in irregularities of the canal surface. Cross-sectional analysis (Fig. 1J) revealed incomplete elimination of gutta-percha across all canal thirds.

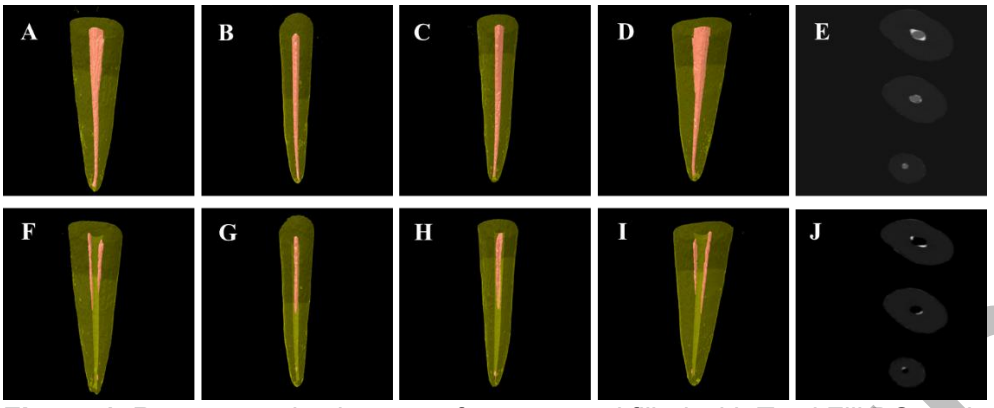

Figure 1. Representative images of a root canal filled with Total Fill BC sealer and a gutta-percha cone before (A–E) and after (F–J) removal using the R-Endo file system. Panels A–D depict mesial, buccal, lingual, and distal views, respectively; panel E shows cross-sectional images at the cervical, middle, and apical levels. Panels F–I present the corresponding post-removal views, and panel J shows the post-removal cross-sections of the same regions.

Figure 2 illustrates the morphological changes in a root canal obturated with BioRoot RCS sealer and a gutta-percha cone before and after retreatment with the XP-Endo Retreatment file system. Pre-removal images (A–E) show uniform, dense filling of the canal space across all surface views and cross-sections. Post-removal images (F–J) reveal a pronounced reduction in filling material, particularly in the cervical and middle thirds, with relatively cleaner canal walls in these regions. However, residual material persists in the apical third and within canal surface irregularities. Cross-sectional views after retreatment (panel J) confirm incomplete elimination of gutta-percha and sealer, with remnants most prominent apically.

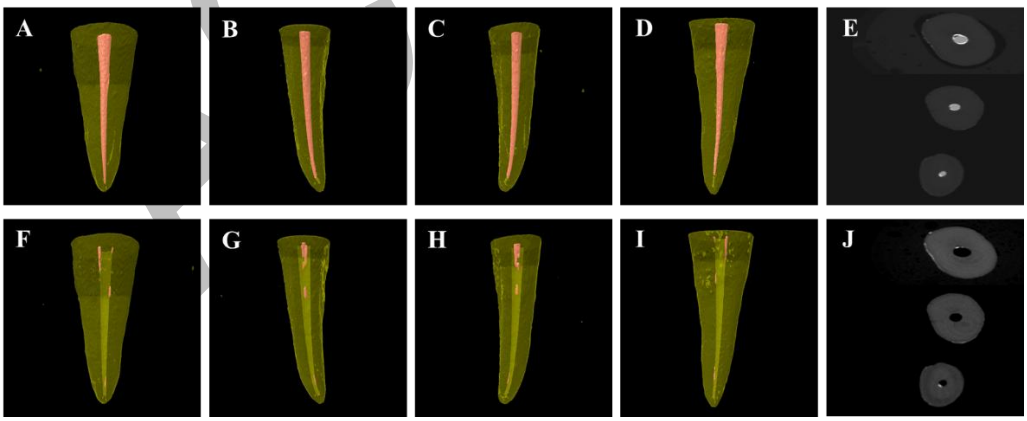

Figure 2. Representative images of a root canal filled with BioRoot RCS sealer and a gutta-percha cone before (A–E) and after (F–J) removal using the XP-Endo Retreatment file system. Panels A–D depict mesial, buccal, lingual, and distal views, respectively; panel E shows cross-sectional

images at the cervical, middle, and apical levels. Panels F–I present the corresponding post-removal views, and panel J shows the post-removal cross-sections of the same regions.

Figure 3 demonstrates the pre- and post-retreatment morphology of a root canal obturated with Total Fill BC sealer and a gutta-percha cone following the use of the HyFlex Remover file system. Before retreatment (A–E), the obturation appears dense and continuous throughout all canal views and levels. After retreatment (F–J), a notable reduction in filling material was observed, particularly in the middle and apical thirds, resulting in visibly cleaner canal walls in these regions. Nevertheless, residual material remains adherent, predominantly in the cervical third within anatomical surface irregularities. Post-removal cross-sections (panel J) confirm incomplete elimination of gutta-percha and sealer in all thirds, with the highest concentration of remnants cervically.

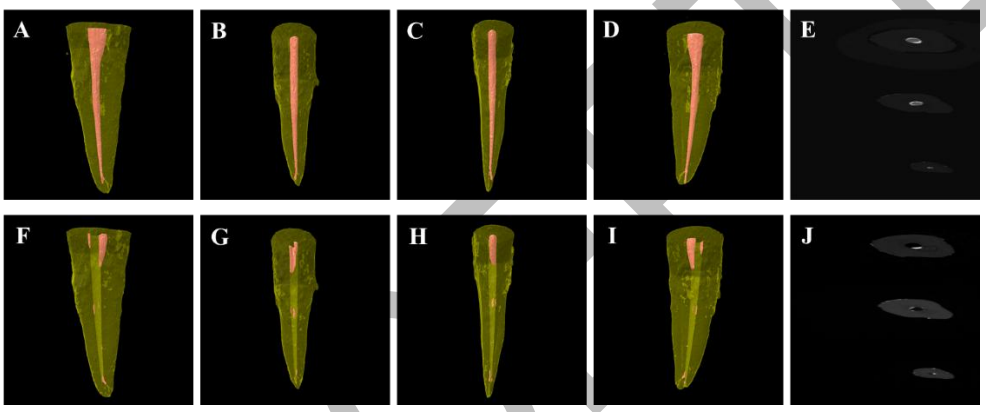

Figure 3. Representative images of a root canal filled with Total Fill BC sealer and a gutta-percha cone before (A–E) and after (F–J) removal using the HyFlex Remover file system. Panels A–D depict mesial, buccal, lingual, and distal views, respectively; panel E shows cross-sectional images at the cervical, middle, and apical levels. Panels F–I present the corresponding post-removal views, and panel J shows the post-removal cross-sections of the same regions.

Figure 4 demonstrates the pre- and post-retreatment morphology of a root canal obturated with BioRoot RCS sealer and a gutta-percha cone following the use of the MicroMega Remover file system. Before retreatment (A–E), the obturation appears dense and continuous throughout all canal views and levels. After retreatment (F–J), a notable reduction in filling material was observed in all canal thirds, resulting in visibly cleaner canal walls. Nevertheless, residual material remains adherent within anatomical surface irregularities. Post removal cross sections (panel J) confirm incomplete elimination of gutta-percha and sealer in all thirds, with the highest concentration of remnants apically.

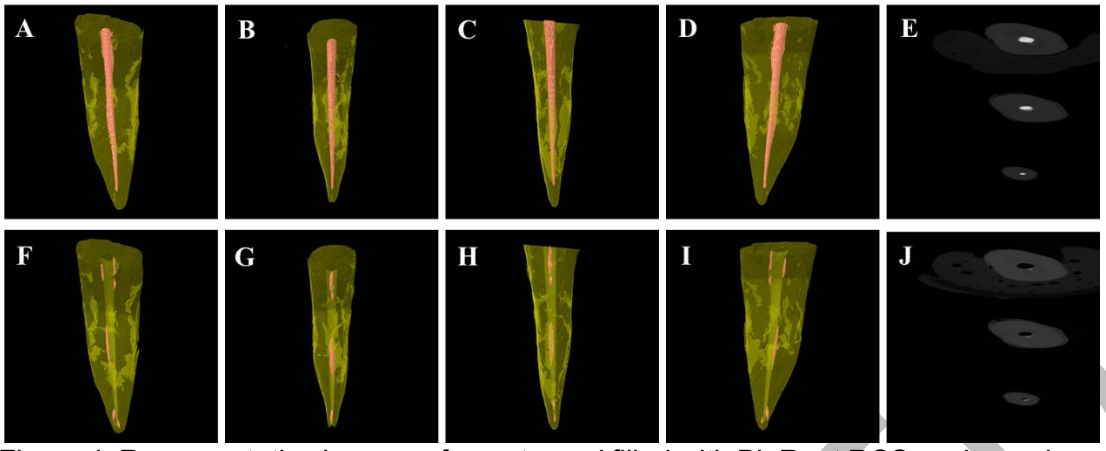

Figure 4. Representative images of a root canal filled with BioRoot RCS sealer and a gutta-percha cone before (A–E) and after (F–J) removal using MicroMega Remover file system. Panels A–D depict mesial, buccal, lingual, and distal views, respectively; panel E shows cross-sectional images at the cervical, middle, and apical levels. Panels F–I present the corresponding post-removal views, and panel J shows the post-removal cross-sections of the same regions.

Discussion

This study evaluated the efficacy of four contemporary retreatment file systems—R-Endo, XP-Endo Retreatment, HyFlex Remover, and MicroMega Remover—in the solvent-free retreatment of root canals obturated with master gutta-percha cone and calcium silicate–based sealers. Characterized by their distinct flute designs, the performance of four retreatment file systems was assessed on standardized root canal specimens filled with either TotalFill BC or BioRoot RCS and aged for one year. The incorporation of high-resolution micro-CT facilitated accurate, non-invasive quantification of residual filling materials, yielding comprehensive three-dimensional insights into the retreatment capabilities of these file systems. The findings indicate that flute design of retreatment file systems significantly influenced the removal efficacy of aged bioceramic sealers under solvent-free conditions, supporting the rejection of the null hypothesis.

All file systems achieved a 100% patency rate, likely due to the retreatment performed in straight canals. The findings unequivocally demonstrated that the geometric and metallurgical properties of the retreatment files markedly influenced their ability to remove aged bioactive calcium silicate–based sealers and the associated gutta-percha filling material. Notably, the XP-endo Retreatment and HyFlex Remover instruments exhibited superior efficacy, with mean removal values exceeding 84% in the middle and cervical thirds of the canals. The XP-endo Retreatment system, fabricated from MaxWire alloy, is

distinguished by its capacity for phase transformation at body temperature and its “envelope of motion” mechanism, which enables dynamic adaptation to canal irregularities [13]. The XP-Endo Retreatment features a slender profile with a narrow taper, a snake-like design, and a booster tip that expands at body temperature. This configuration maximizes contact with the canal walls, thereby enhancing cleaning efficiency, while the file’s design and the rapid high-speed plasticization of gutta-percha likely facilitate its removal [5, 13]. This property likely facilitated enhanced wall contact and material disruption, particularly in anatomically complex sections.

Despite being a single-file system, the HyFlex Remover benefited from its variable taper and optimized cutting geometry with rectangular flute design, which facilitated efficient engagement and removal of both gutta-percha and aged bioceramic sealer. In addition, the thermomechanical treatment of the HyFlex alloy enhances its flexibility, allowing the file to better adapt to canal curvatures and maintain consistent contact with the canal walls during retreatment [17]. The high removal efficiency of HFR, especially in the middle and coronal thirds, can be attributed to the combination of its rectangular cross-section and continuous rotation motion, which together enhance cutting efficiency and debris transportation.

While a previous study reported the effectiveness of the R-Endo file system in initial canal penetration [11] , and another suggested that its three equally spaced cutting edges, absence of radial lands, and inactive tip facilitate gutta-percha removal [21], the findings of the present study demonstrated otherwise. The R-Endo system consistently exhibited the lowest removal efficiency across all canal regions, particularly in the apical third. Its conventional nickel–titanium construction, limited flexibility, and reliance on a crown-down sequence may have hindered adaptability in navigating apical restrictions without the use of solvents [3]. The inactive tip, although intended to reduce canal transportation, may have further limited penetration into compacted filling material, while the absence of radial lands can impair the instrument’s capacity to scrape residual material from broad canal walls. These design and operational factors, combined with the absence of solvents, may collectively explain the poor performance observed in all canal levels.

The MicroMega Remover demonstrated intermediate performance, superior to R-Endo but inferior to XP-Endo Retreatment and HyFlex. This performance differential can be attributed to specific flute design (*i.e.*, s-shaped) and operational characteristics of the MicroMega Remover file system. Notably, the MicroMega Remover features a continuous rotation motion with a relatively straight file design and a moderately aggressive cutting profile, which enables efficient mechanical disruption and removal of gutta-percha and sealer material without the use of solvents. However, its less flexible, non-adaptive design limits its ability to conform to the complex three-dimensional anatomy of root canal systems, constraining its penetration depth into apical and middle thirds. The file is designed with a non-cutting tip, providing safety by reducing the risk of apical transportation, yet potentially limiting direct engagement with compacted filling material lodged apically. The cross-sectional geometry and taper of the MicroMega Remover balance cutting efficiency with preservation of dentin, but this also may reduce its aggressiveness compared to more taper-variable and alloy-modified instruments such as XP-Endo Retreatment and HyFlex Remover. Since the Micro-Mega REMOVER is a relatively recent market introduction (launched around 2020), there is currently no available data comparing its performance directly with contemporary file systems in endodontic retreatment.

Neither system was able to completely remove the intracanal filling from all root canals. A finding attributable to the apical third's smaller canal diameter, increased dentinal density, and complex morphological architecture, and consistent with previous reports [6, 7]. This persistent challenge impedes instrument contact and debris evacuation. The deliberate omission of chemical solvents in this study, in alignment with emerging clinical paradigms favoring solvent-free retreatment, further accentuated these anatomical constraints, thereby enhancing the clinical relevance of the findings for practitioners who eschew chemical softening agents. These results align with recent investigations demonstrating that effective removal of calcium silicate–based sealers remains challenging without the use of solvents, underscoring the mechanical limitations inherent in current instruments [8, 12].

No statistically significant differences were observed in removal efficiency between the two calcium silicate–based sealers—Total Fill BC and BioRoot RCS. Despite potential disparities in their physicochemical properties, such as radiopacity, particle size, and hydration dynamics, both sealers posed similar mechanical resistance to instrumentation after prolonged aging. This outcome is supported by recent systematic reviews, which indicate that calcium silicate–based sealers, despite brand-specific variations, consistently exhibit robust interfacial bonding that limits their retrievability [2, 16]. The absence of a significant interaction between sealer type and file system further suggests a consistent hierarchy of file system performance across different bioceramic sealer brands.

For clinicians undertaking solvent-free retreatment of root canals filled with bioceramic sealers, the use of file systems engineered with adaptive kinematics and advanced alloy technology, such as the XP-endo Retreatment system or the HyFlex Remover, is advisable due to their enhanced effectiveness. However, complete elimination of sealer remnants, particularly in the apical region, is seldom achievable. To optimize debridement, the integration of these rotary systems with effective irrigation activation strategies is essential. Adopting such an evidence-based protocol contributes to greater retreatment predictability and reinforces the clinical applicability of solvent-free approaches in modern endodontic practice. Future research should validate these findings in curved canals, evaluate the synergy between top-performing files and advanced irrigation activation, and develop novel instrument designs specifically engineered to overcome the challenge of removing adhered bioceramic materials.

Conclusion

Within the limitations of this laboratory study on straight root canals, the choice of retreatment file system significantly influenced the efficacy of aged bioceramic sealer removal under solvent-free conditions. XP-Endo Retreatment and HyFlex Remover demonstrated superior efficacy, particularly in the middle and coronal thirds, likely due to their adaptive designs, metallurgical enhancements, and optimized cutting geometries. Conversely, Remover exhibited intermediate performance, outperforming R-Endo but remaining less effective than the aforementioned systems, reflecting the influence of file

flexibility, taper, and cross-sectional design on retreatment efficiency. While these laboratory findings provide valuable insight into the mechanical performance of different file designs, clinical validation is necessary to confirm these outcomes in the more complex environment of vital cases and curved root canals.

Conflict of interest

The author declares no any conflict of interest.

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