Proceeding Paper

Tomographic Evaluation of the Efficacy of Three Rotary Retreatment Systems for Retreatability of Root Canals Obturated with Two Different Techniques [†]

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Abstract: The objective of this in vitro study was to compare the efficacy of three different rotary systems, namely D-RaCe, R-Endo, and Edgefile XR, in the removal of root canal obturation materials during non-surgical retreatment procedures. Lower first premolars with straight oval canals were utilized, and microcomputed tomography (micro-CT) was employed as an evaluation method. The study also aimed to investigate the influence of two different initial obturation methods, the single cone and the continuous wave compaction techniques, on the amount of residual material after retreatment. The findings revealed that none of the retreatment systems could completely eliminate the obturation material, corroborating existing studies. However, Edgefile XR outperformed the other systems in terms of reduced residual material. The continuous wave compaction method for initial obturation resulted in fewer remnants compared to the single cone technique. This contradicts prior research suggesting that the two methods offer comparable sealing abilities. The study underscores the advantages of using micro-CT for evaluation, as it provides a more accurate three-dimensional assessment of the residual materials in the canals. Despite its limitations, such as the focus on straight canals and the in vitro setting, the study provides crucial insights for clinicians. It suggests that the choice of rotary system and initial obturation method can significantly impact the success of root canal retreatment procedures.

Keywords: root canal retreatment; D-RaCe; R-Endo; Edgefile XR; microcomputed tomography; continuous wave compaction; single cone technique; residual material

1. Introduction

Non-surgical endodontic retreatment aims to re-establish healthy periapical tissues following unsuccessful initial treatment or reinfection of an obturated root canal system due to coronal or apical leakage [1]. The objective is to eliminate infected obturating material and dentin, as well as to negotiate the apical foramen to ensure patency. Such measures facilitate a decrease in bacterial levels by removing the existing filling material, thereby enhancing the instrumentation and irrigation of the entire root canal system [2,3]. While root canal treatment is generally considered safe and effective, boasting a success rate of up to 93% when professionally conducted [4], failures still occur. These are often attributable to a myriad of factors, such as non-compliance with standard protocols, inadequate root canal instrumentation, microbial persistence, poor obturation quality, and both under- and over-extended root canal filling materials [5]. A major cause of such failures is the persistence or reentry of microorganisms within the root canal system due to inadequate seals [3]. Removing obturating materials from improperly prepared or filled root canals presents a considerable challenge. Various methods are employed for this purpose, including hand files, burs, solvents, lasers, ultrasonic instruments, and rotary instruments like Gates

Glidden drills. More recently, Nickel–Titanium (NiTi) rotary files and reciprocating systems have been developed specifically for retreatment procedures [6].

Notable examples include the Edgefile XR (EdgeEndo, Albuquerque, NM, USA), D-Race (FKG, La Chaux-de-Fonds, Switzerland), and R-Endo (Micro-Mega, Besancon, France), all designed for the removal of root canal obturating materials [7]. However, no single retreatment technique guarantees the complete removal of root canal filling materials. Several methods have been proposed for measuring residual material, such as radiographs, teeth sectioning, stereomicroscopy, cone beam computed tomography (CBCT), and micro-computed tomography (micro-CT) [8]. Among these, micro-CT stands out as a non-invasive, accurate imaging modality for analyzing residual root canal filling material without the need for physical manipulation of the sample [9,10]. Micro-CT technology has become increasingly relevant in endodontic imaging of hard tissue. It offers both qualitative and quantitative three-dimensional imaging capabilities, thereby facilitating the evaluation of root canal systems [11]. Its non-destructive and reproducible nature allows for comparative studies of root canal parameters such as volume, surface area, and deviation [12]. Furthermore, some studies have employed micro-CT techniques to evaluate the debris removal efficacy of different NiTi instruments with specific designs [13]. Understanding the variables and technical challenges in achieving the complete removal of root canal filling material during retreatment is of paramount importance for clinicians aiming to improve treatment outcomes.

2. Materials and Methods

2.1. Eligibility Criteria for the Teeth

The study included forty-two human mandibular first premolars, recently extracted for orthodontic purposes and belonging to individuals aged between 35 and 45 years. The sample size was determined based on a review of relevant literature. Eligibility criteria for the teeth included the presence of single straight canals, the absence of caries, completely formed roots, no evidence of calcification, and no external or internal resorption. Additionally, the teeth must not have undergone any previous root canal treatment. To confirm these criteria, each selected tooth was subjected to periapical radiography in both buccolingual and mesiodistal directions [14].

2.2. Preparation of Samples

The teeth selected for this study were initially cleaned to remove calculus, plaque, and other residual debris. Subsequently, they were stored in distilled water at room temperature until required for the experiment. The teeth were then decoronated to a length of 14 mm from the apex using a digital Vernier caliper as a measuring aid. Decoronation was performed with a diamond disc (KG Sorensen Ind. Com Ltd., Cotia, SP, Brazil) under water coolant at a low speed. Access cavity preparation was carried out using a round diamond bur attached to a high-speed handpiece, supplemented by a water cooling spray. The working length of each tooth was established by inserting a #10 k-file (Mani, Inc., Tochigi, Japan) into the canal until the apex was visible, thus confirming patency. The working length was set 1 mm shorter than the apical foramen's location. Subsequent to cavity cleaning and shaping, the root canals were rinsed with a total of 10 mL of 2.5% sodium hypochlorite solution (Chloraxid, Medical Company, Stalowa Wola, Poland). To achieve this, a #10 manual k-file was initially introduced into the canal to locate the canal path [15].

2.3. Instrumentation of Root Canal

For greater standardization during the root canal preparation and filling phases, all specimens were placed within a silicone impression block measuring 2 cm × 2 cm × 2.5 cm. The block was clamped in a bench vice to ensure consistent positioning during both the preparation and filling stages. A single operator instrumented all root canals using the One Curve (OC; Micro Mega, Besancon, France) rotary system attached to a contra-angled

handpiece. The procedure began with a one-flare instrument to remove 4 mm ± 1 mm at a speed of 300 rpm and a torque of 2.5 N/cm. This was followed by mechanical preparation using a G-size (15) instrument at the same speed but a reduced torque of 1.2 N/cm.

All canals were then prepared using a one curve (25.04) single file at the same speed and torque settings as the one flare. Each instrument was discarded after preparing three canals [16]. Throughout the instrumentation process, the canals were irrigated after each file use with a 2.5% sodium hypochlorite solution (Chloraxid, Medical Company, Stalowa Wola, Poland) using a 30-gauge needle (Sinalident, China). Subsequently, 17% EDTA (PD, Rue des Bosquets, Vevey, Switzerland) was employed to rinse the canals for one minute to remove the smear layer. The root canals were then given a final irrigation with 5 mL of 2.5% sodium hypochlorite, followed by a 2 min rinse with 5 mL of distilled water to remove any residual irrigating solution. The canals were dried using paper points (25.04) (GAPADENT®, Tianjin, China).

2.4. Techniques of Obturation

The obturation techniques for each group were performed as follows:

- **Group A: Single Cone** (n = 21): A gutta-percha cone of size 25.04 was used to measure the working length and perform a tug-back test. AH Plus Sealer (Dentsply Detrey Gmbh, Konstanz, Germany) was mixed and applied to the canal using a paper point. The gutta-percha cone was also coated with the sealer before insertion into the root canal. Excess material was then removed using a heated spoon excavator [17].
- **Group B: Continuous Wave Compaction** (n = 21): The entire working length of the canal was reached using a gutta-percha cone of size 25.04, followed by a tug-back test. The sealer was then mixed and applied to the canal walls using a paper point. The tip of the gutta-percha cone, coated with sealer, was inserted into the root canal. The Fast Pack device (Eighteeth Medical, Chang-Zhou, China) was set to 200 °C. A heated plugger with a medium-sized tip was introduced after placing a rubber stop 3–5 mm from the working length. The canal was filled incrementally with gutta-percha every 3 mm. The Fast Pack was then set to 180 °C for easier placement of the softened gutta-percha into the remaining anatomical spaces [15,18].

2.5. Post-Obturation Procedures

After obturation and prior to sample removal from the block, a 4 mm-thick layer of Tetric N-ceram composite resin was used to restore all roots and ensure an optimal coronal seal. The quality of the root canal filling was evaluated using periapical radiographs from both buccolingual and mesiodistal perspectives [15]. Samples with defective or insufficient obturation were excluded from the study. All specimens were stored at 37 °C in 100% humidity, wrapped in gauze moistened with distilled water, for four weeks to simulate clinical conditions and ensure the complete setting of the root filling material.

2.6. Micro-CT Evaluation and Analysis

After embedding the samples in a silicone impression material block measuring 2.5 cm × 2 cm × 2 cm [15], they were scanned using a high-resolution desktop micro-CT system (Bruker Skyscan 1275, Kontich, Belgium). The objective was to evaluate the total volume of the root filling material prior to retreatment. Scanning parameters included a 0.5-step rotation, 11.2 μm pixel size, 0.5 mm Al/Cu filter, 100 mA beam current, and 100 kVp voltage. The detector was calibrated with air prior to each scan to minimize ring artifacts. Each specimen underwent a 360° rotation within an approximate time span of 5 min, with the average scan duration totaling about 2 h.

Data visualization and quantification were performed using NRecon (ver. 1.6.10.4, SkyScan, Kontich, Belgium) and CtAn (ver. 1.17.7.2, SkyScan). A modified algorithm was employed to generate axial, two-dimensional images with a resolution of 1000×1000 pixels. The NRecon software, (ver. 1.6.10.4) was utilized for image reconstruction, resulting in 2-dimensional slices of the roots. CtAn software, (ver. 1.17.7.2) was then used to measure the pre-instrumentation images, calculating the root canal filling volume in cubic millimeters (mm^3). For further visualization, the reconstructed images were processed using Skyscan CTVox (ver. 3.3.0, SkyScan).

2.7. Retreatment Technique

Upon completion of the micro-CT scanning, the teeth were randomly allocated into three groups (n = 7) for retreatment using D-Race, R-Endo, and Edgefile-XR systems. The same operator performed the retreatment procedures using an Endomate micromotor (X-smart Plus, Dentsply Maillefer, Switzerland), following the manufacturer's instructions.

- **Group A1 and B1:** D-Race System: The D-Race rotary retreatment system (FKG Dentaire, La Chaux-de-Fonds, Switzerland) comprises two distinct files: DR1 (30/0.10) and DR2 (25/0.04). The DR1 file, designated for the coronal third, operates at a speed of 1000 rpm and a torque of 1.5 N/cm. Conversely, the DR2 file is used for the middle and apical thirds at 600 rpm and 0.7 N/cm torque. The DR1 files were discarded after four uses, while the DR2 files were discarded after a single use [19].
- **Group A2 and B2:** R-Endo System: The R-Endo retreatment system consists of three files: R1 (25/0.08) for the coronal third, R2 (25/0.06) for the middle third, and R3 (25/0.04) for the apical third. All files were used at a speed of 300 rpm and a torque of 1.2 N/cm. Each file was discarded after five uses.
- **Group A3 and B3:** Edgefile-XR System: EdgefileXR rotary retreatment files were employed in the following sequence: R1 (25/0.12), R2 (25/0.08), R3 (25/0.06), and R4 (25/0.04). The procedures were conducted at 400 rpm and a torque of 3 N/cm. Each file was discarded after four uses.

During the retreatment process, a 30-gauge needle was used for root canal irrigation with 5 mL of 2.5% sodium hypochlorite solution (Chloraxid, Medical Company, Poland) after each file change. Subsequently, the canals were irrigated with 5 mL of 2.5% sodium hypochlorite following a one-minute rinse with 17% EDTA. Finally, the canals were rinsed with 5 mL of saline solution and dried using paper points. The criteria for successful retreatment included reaching the full initial working length, having smooth canal walls, and the verified absence of residual root filling material on the instruments [2,19].

2.8. Micro-CT Scans after Root Canal Filling Removal

A Bruker Skyscan 1275 micro-CT scanner (Kontich, Belgium) was employed to quantify the residual filling material on the dentinal walls of the canals in each group (Figure 1). The volumetric percentage of cleaning efficacy for each rotary system was calculated using the following Equation (1) [15]:

$$\text{Remaining filling material \%} = \left(\frac{\text{Volume of residual filling material}}{\text{Volume of total filling material}} \right) \times 100 \quad (1)$$
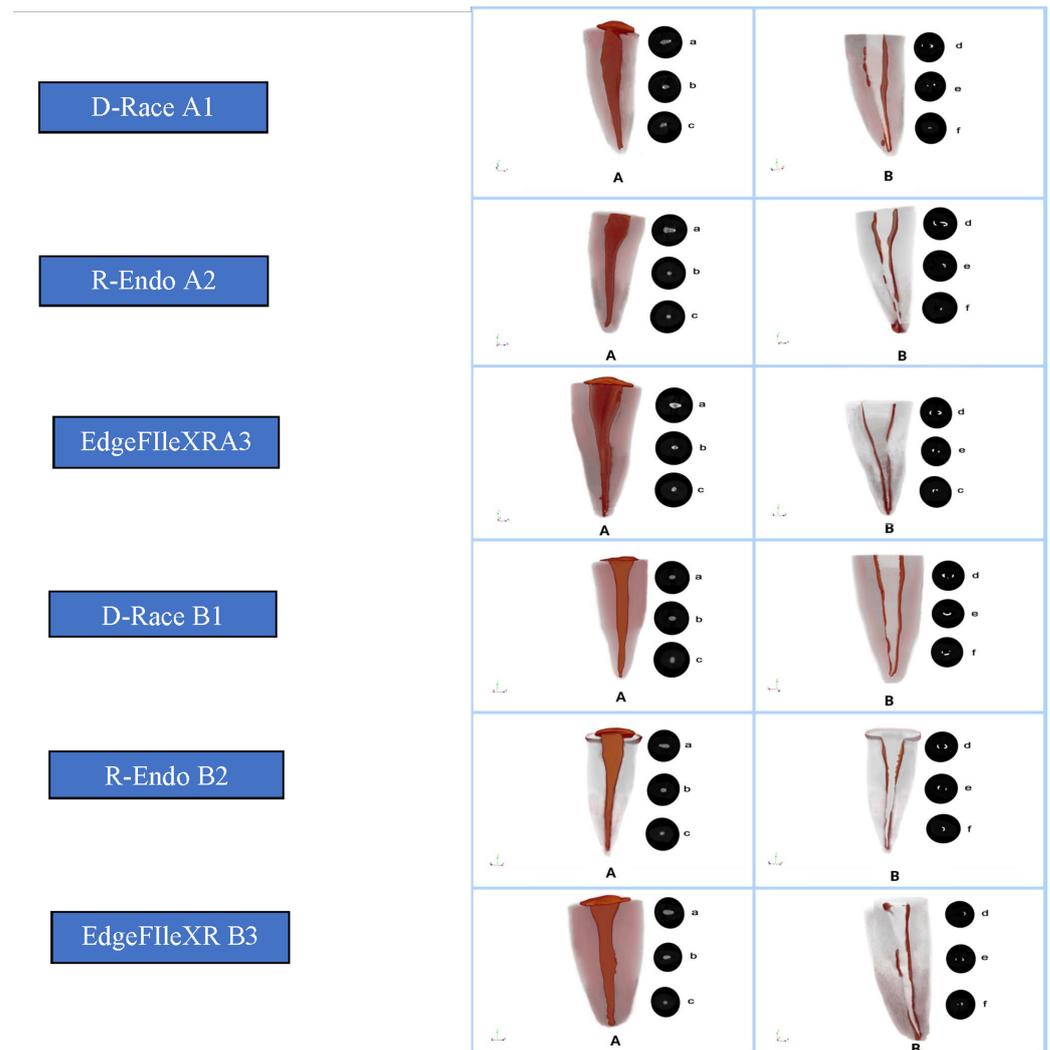
Figure 1. 3D reconstruction (A) after obturation and (B) after retreatment procedures, as well as horizontal section images (d, e, f) of the axial section of the samples from the D-Race (A1, B1), R-Endo (A2, B2), and EdgeFile XR (A3, B3) groups for both obturating techniques. (A) After obturation and (B) after retreatment procedures, micro-CT scans of horizontal sections at the cervical, middle, and apical levels were obtained after both obturation (a, b, c) and retreatment (d, e, f).

3. Results

Statistical Analysis

Statistical analysis was performed using SPSS software version 23 (IBM, Armonk, NY, USA). A one-way Analysis of Variance (ANOVA) was employed to test for statistical differences at the confidence level $p < 0.05$ between groups. Post hoc Duncan analysis was subsequently applied to pinpoint the specific locations of differences among the groups.

Table 1 displays the median, minimum, maximum, and standard deviation values for the percentage of residual root filling material following root canal retreatment. Additionally, the median values of residual root filling material for the different groups are presented in Figure 2. The ANOVA test revealed no statistically significant differences between the groups in Group A ($p > 0.05$). In contrast, significant differences were observed in Group B ($p < 0.05$). Specifically, the Edgefile XR system left fewer residual filling materials compared to R-Endo and D-RaCe in both groups. Post hoc analysis indicated no significant difference between Edgefile XR and R-Endo, but a significant difference was observed compared to D-RaCe when employing the continuous wave technique.

Table 1. Descriptive statistics of the percentage of total residual filling material between groups in both obturation techniques (%).

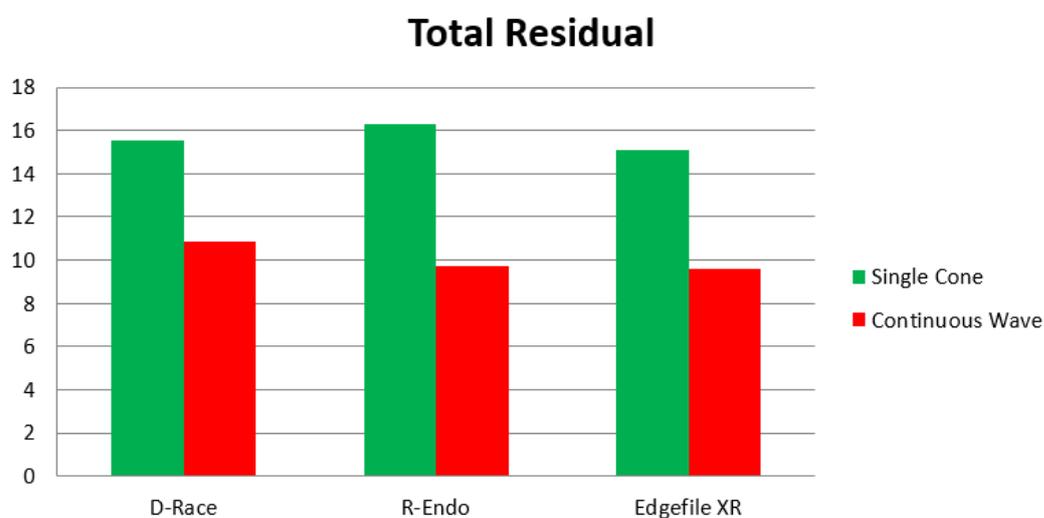| Groups	No.	Mean %	Std. Deviation %	Minimum %	Maximum %
A1 D-RaCe	7	15.54	1.96	13.38	18.32
A2 R-Endo	7	16.30	1.31	14.23	17.64
A3 (Edgefile XR)	7	15.07	1.67	12.55	17.50
Total for Group A	21	15.64	1.66	12.55	18.32
B1 D-RaCe	7	10.86	0.76	9.95	12.05
B2 R-Endo	7	9.73	0.63	8.87	10.68
B3 (Edgefile XR)	7	9.58	0.99	7.95	10.92
Total for Group B	21	10.06	0.96	7.95	12.05

Figure 2. Bar chart showing the mean percentage of remaining obturating material for each of the different retreatment systems that use continuous wave techniques and single cone.

4. Discussion

The complete removal of root canal obturation materials is imperative for effective non-surgical retreatment. This allows for comprehensive access of instruments and irrigating solutions to the entire canal system, thereby promoting superior cleaning and disinfection. The complexity of canal retreatment is exacerbated by several challenges, including flare-ups and treatment failure. These issues often arise due to necrotic tissues and bacterial contamination associated with residual root canal obturating materials [1]. In the present study, lower first premolars with straight, oval canals were utilized. Such teeth are often extracted for orthodontic purposes, making them readily available in a healthy state for in vitro endodontic research. Additionally, the anatomical complexity of these canals is a critical factor to consider during retreatment procedures [20]. Mandibular premolars often feature complex root canals with oval and elongated cross sections, making them particularly challenging to treat or retreat. These complexities are amplified by buccal and lingual surface extensions, which may be difficult to access, even with advanced endodontic instruments. Instrumentation for all samples was conducted using the One Curve rotary system with a 25/0.04 configuration. This was performed to ensure uniformity in the volume of obturating material across all samples. Micro-CT was employed as the evaluation methodology for this study. The divergence in results between this study and previous research may be attributed to the utilization of different methodologies. In particular, the three-dimensional analysis provided by micro-CT offers greater accuracy since two-dimensional methods are incapable of identifying residues within dentinal tubules.

Various methodologies have been employed to assess residual material in the root canal following retreatment. These include sectioning, radiography, dental operation microscopy, computed tomography (CT), scanning electron microscopy, cone-beam computed tomography, and micro-CT [15]. Micro-CT offers several advantages, such as preserving the structural integrity of samples, repeatability, and the capability for three-dimensional evaluation [21]. Given these benefits, micro-CT has recently become a popular choice for evaluating the efficacy of root filling material removal. It offers both the qualitative and quantitative assessment of three-dimensional morphological features. Consequently, this study opted for microcomputed tomography evaluations, given its superior accuracy compared to other currently available techniques. In the context of non-surgical root canal retreatment, it is crucial to completely remove existing root canal obturating materials. This is essential for bacterial elimination, enhancing the efficacy of irrigating solutions and intracanal medicaments, and ensuring optimal sealing for the newly placed root filling material. In this study, complete removal of the root canal filling material was not achieved by either retreatment method, corroborating the findings from other research [9].

The complexities inherent to root canal anatomy, along with the limited accessibility of the instrumentation, render the total elimination of root filling materials an unlikely outcome [2]. Despite the absence of statistically significant differences among the groups, the Edgefile-XR system was observed to remove the most root canal filling material. Particularly in Group B, significant differences were noted between the R-Endo and Edgefile XR systems when compared to D-Race. Thus, the study's null hypothesis was rejected. The present study revealed a lower percentage of residual material post-retreatment in teeth filled using the continuous wave compaction method, as opposed to those obturated with the single cone technique (R-Endo, D-Race, and Edgefile XR). Previous research comparing the obturation volume and sealing ability between these two methods did not find any significant differences [22]. Therefore, the observed differences in residual filling material within the canals between the two obturation techniques employed in this study cannot be accounted for by prior research using the same retreatment systems.

In previous studies employing computed tomography, such as that by Barletta et al. [9], assessing the elimination of root filling material based on root canal thirds was not feasible. This limitation was due to the lack of microcomputed tomography software tools allowing for the segmentation of the specimen into equitable thirds [19]. In Group A, D-RaCe demonstrated lower percentages of residual filling material throughout the entire canal compared to R-Endo. This outcome aligns with the findings of Rödig et al. [19], who ascribed the high efficiency of D-RaCe files to the availability of deep space on the rear of the blades, allowing for the enhanced removal of dentinal debris. EdgefileXR files showed less residual filling material than did the R-Endo and D-Race NiTi rotary retreatment systems. This is consistent with the study by Tomer et al. [7], which found EdgeFile XR instrumentation to have superior efficacy in terms of residual material, albeit with no statistically significant difference from R-Endo. Given the limited research on Edgefile XR, its superior performance may be attributable to its composition of annealed, heat-treated Ni-Ti alloy, known as Fire-Wire^{TM}. This alloy enhances performance durability, providing the file with exceptional flexibility and superior results in cyclic fatigue testing, a critical indicator of file durability and strength. Edgefile XR thus expedites and improves root canal retreatment. Its parabolic cross-section design combines instrument flexibility with high efficiency, offering both fracture resistance and enhanced safety. According to the current study protocol, R-Endo and EdgefileXR left nearly equivalent amounts of residual filling material on the canal walls.

In the present study, the total residual material in group B (B1, B2, B3) revealed that B1 had the highest amount of remaining material. This observation is consistent with the findings of Marques da Silva et al. [23], who noted that D-RaCe was less effective in the absence of additional instruments. The authors attributed this limitation to the design of the DR2 file, which is thinner and features an inactive tip, thereby complicating the penetration of gutta-percha. Furthermore, the study showed that the overall residual amounts of the

gutta-percha and sealer in group B were lower compared to group A. This could be related to the properties of the AH Plus sealer, an epoxy resin-based sealer. Upon heating, the sealer undergoes chemical changes, including the decomposition of n-h bonds, leading to a reduction in both the setting time and material strength, as well as an increase in the flow and film thickness [24]. In a recent retreatment investigation by Keleş et al. [24], two filling techniques in oval canals were compared. The study found that the warm vertical condensation group, which employed incremental downpack and backfill techniques, retained less filling material compared to the CLC group. The superior performance was attributed to higher bond strength, better sealer–dentine contact, and the sealer's ability to penetrate dentinal tubules. Moreover, the use of thermomechanical compaction produced a non-uniform structure, suggesting that the plasticized filling material infiltrated the sealer [24]. Scanning electron microscopy (SEM) studies have further shown that the cooling and shrinking of the solid material result in sealer retraction and crater formation, thereby weakening the adhesive interface [25]. Moreover, heating the AH Plus sealant is likely to speed up the polymerization process, resulting in reduced flow rates [26].

Consequently, thermoplasticized gutta-percha may only achieve mechanical interlocking when penetrating canal micro-irregularities and dentinal tubules, as the absence of sealer could compromise adhesion [25]. The Edgefile XR system demonstrated superior performance in removing obturation material across both types of obturation techniques. This could be attributed to the system comprising four files, as opposed to the three-file R-Endo system. This numerical difference likely influenced the efficacy of material removal [27–29]. In contrast, the D-RaCe system, with only two files, was less effective in this regard. It is worth noting that variations in findings across different studies may stem from the use of various instruments, types of teeth, canal curvatures, techniques, and methodologies. Limitations of this study include the focus on straight canals, rendering the results not directly applicable to curved canals. Furthermore, the in vitro nature of the study, conducted on mandibular first premolars, limits the generalizability of the findings to a clinical setting or to other types of teeth. The impact of the operator's skill level and experience should also be considered when interpreting the results.

5. Conclusions

In summary, this study aimed to evaluate the efficacy of three different rotary systems—D-RaCe, R-Endo, and Edgefile XR—in removing root canal obturation material during non-surgical retreatment procedures. The results indicated that none of the systems could completely remove the obturation material, which is consistent with previous literature. However, Edgefile XR exhibited superior performance in terms of the least amount of residual material. Additionally, the continuous wave compaction method for initial obturation was found to have fewer remnants compared to the single cone method, although prior research suggests no significant difference in sealing ability between the two. The use of micro-CT scanning as an evaluation method provided a more accurate and detailed three-dimensional analysis of the residual materials. Despite its limitations, such as the focus on straight canals in mandibular first premolars, the study offers valuable insights that could guide clinicians in selecting the most appropriate rotary system and obturation method for root canal retreatment. Future studies could expand on these findings by considering curved canals and different types of teeth, and by evaluating the outcomes in a clinical setting.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the data used in the experiment have been made available in the present article.

Conflicts of Interest: The authors declare no conflicts of interest.

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