EUROPEAN ENDODONTIC JOURNAL

ORIGINAL ARTICLE

Impact of Different Nickel-titanium Instruments on Apical Micro-cracks Formation and Residual Amount of Root Canal Filling Materials Following Retreatment Procedure

Ahmed Maytham WITWIT, Maha YAHYA ALBAZZAZ, Baidaa Mohammed ZEIDAN

Department of Operative Dentistry, College of Dentistry, Mustansiriyah University, Baghdad, Iraq

ABSTRACT

Objective: This study aimed to evaluate and compare the dentinal defects caused by three different retreatment systems [Endostar RE Endo, XP-endo Retreatment, and MANI Gutta-Percha Removal (GPR)] and to assess the percentage of residual root canal filling material following the retreatment procedure.

Methods: Sixty extracted mandibular second premolars with straight oval canals were used. The roots were standardized to a length of 14 mm. All samples were instrumented with NiTi instruments up to size 30.04, then filled using single cone technique with AH plus sealer and gutta-percha. Four groups were created from the samples. Group 1 served as the negative control (n=15), while the remaining three groups (n=15 each) were categorized based on the retreatment system used. Stereomicroscope at magnification 45 x was used to evaluate the incidence of crack formation and propagation at apex of the roots and the residual volume percentage of root filling materials in groups of Endostar RE, MANI GPR, Xp retreatment systems assessed using CBCT. Fisher's exact test was used to analyze the incidence and propagation of cracks, while one-way ANOVA and Tukey's post hoc test were applied to assess differences in residual filling material volume among the groups P values at 0.05.

Results: There is significance difference (p=0.028) between the Endostar and Xp retreatment system. The highest of dentinal defect (10\15) with Endostar retreatment system followed by (4\15) with GPR system and (2\15) with XP endo retreatment system.Highest residual filling material mean at Endostar RE retreatment system (51.97) and lowest mean (39.07) at Xp retreatment system A statistically significant difference was observed between the groups (p<0.001), particularly between the Endostar and XP retreatment systems.

Conclusion: No system was capable of completely eliminating obturated materials. The XP-endo Retreatment system showed the lowest incidence of crack formation and propagation and proved to be the most effective in removing gutta-percha and sealer.

Keywords: Crack formation, endodontic retreatment, root-filling material remnant

HIGHLIGHTS

- No system exhibited a zero incidence of crack formation.
- No system was capable of completely removing the gutta-percha and sealer.
- The XP-endo Retreatment system exhibited the lowest incidence of crack formation and propagation, demonstrating superior efficacy in the removal of gutta-percha and sealer.

Please cite this article as:
Witwit AM, Yahya Albazzaz M, Zeidan BM. Impact of Different Nickel-titanium Instruments on Apical Micro-cracks Formation and Residual Amount of Root Canal Filling Materials Following Retreatment Procedure. Eur Endod J 2025; 10: 420-431

Address for correspondence:
Ahmed Maytham Witwit
Department of Operative Dentistry, College of Dentistry, Mustansiriyah University, Baghdad, Iraq
E-mail: ahmedwitwit28@gmail.com

Received : April 03, 2025,
Revised : May 17, 2025,
Accepted : June 16, 2025

Published online: September 09, 2025
DOI 10.14744/eej.2025.09226

INTRODUCTION

Failure after root canal treatment may occur due to the persistence of infection from persistent microorganisms or the reactivation of pathogens within the root canal system via coronal or apical pathways (1). A successful retreatment process involves removing of existing root canal filling material, followed by cleaning, shaping, and obturation stages (2).

Due to their advantages over stainless steel files, NiTi rotary files are being used more and

more in retreatment procedures and root canal therapy. Despite numerous advantages, NiTi rotary systems may lead to dentinal defects, such as crack formation, both during canal shaping and retreatment procedures.There is a concern that compromised dentin resulting from widening procedures may ultimately lead to adverse outcomes such as vertical radicular fractures (3).

Dentinal cracks may form as a result of stress concentration caused by the contact between endodontic instruments and dentin, which, with repetitive occlusal stresses, can propagate and result in complete fracture. Vertical root fractures, a severe complication in endodontic treatment, often result from the gradual propagation of initially undetectable dentinal cracks. Consequently, a primary objective in endodontic research is to minimize the risk of dentinal fracture formation during instrumentation with rotary instruments (4).

Recent studies have focused on the effect of glide path preparation on dentin preservation. The micro-computed tomography images were used to assess the microcracks induced after the application of the different glide path techniques before root canal instrumentation, as reported in study (5). Their results showed that some glide path solutions could have a strong impact on causing dentinal microcracks. Therefore, it is crucial to emphasize careful technique selection when using rotary instruments during retreatment to minimize structural damage.

For many years, a major area of research has been the behavior of rotating instruments in defect creation. The formation and propagation of cracks during procedures using manual, rotary, and reciprocating instruments have been reported in numerous studies (6). Dentinal cracks are structural defects characterized by lines extending from the internal root canal wall to the external root surface, typically occurring when the tensile stress within the canal wall exceeds the strength of the dentin (7, 8).

Successful removal of gutta percha and sealers from the root canal system during retreatment methods can be approached in several ways, some of which involve the use of supplementary chemical solvents and others without. Tools such as lasers, ultrasonic cleaners, heated instruments, nickel-titanium rotary files, gate glidden burs, and stainless steel hand files are utilized in these procedures (8–10).

In spite of the efficacy of all these systems, complete removal of root canal filling materials remains a clinical challenge regardless of the retreatment technique used (11, 12). On the other hand, the type of filling has a direct effect on its elimination (13).

Few studies have compared the Endostar RE Endo System (ERE; Poldent Co Ltd, Poland), XP-endo Retreatment system (FKG Dentaire, Switzerland), and the MANI Gutta-Percha Removal system (MANI, Japan) in terms of their effectiveness in removing filling material and their tendency to induce crack formation and propagation.

This study aimed to evaluate and compare the effect of using three different Niti rotary retreatment systems (The Endostar RE Endo, XP-endo , Mani gutta-percha removal system) on the incidence of microcrack formation and propagation and on the amount of residual root canal filling material following retreatment.

The null hypothesis of this study that the type of NiTi retreatment instrument used has no effect on the occurrence of microcrack initiation or propagation, nor on the percentage of residual root canal filling material.

MATERIALS AND METHODS

Tooth Selection

Sixty extracted human mandibular premolars with comparable lengths, straight roots, and no caries were selected. All teeth were extracted for orthodontic reasons."Ethical approval for this study was obtained from the College of Dentistry Research Ethics Committee at Mustansiriyah University (Approval No. MUOPR29, dated May 1, 2023; REC Reference: REC130)". The study was conducted in accordance with the declaration of Helsinki. Radiographs were obtained from bucco-lingual and mesio-distal aspects to confirm the existence of only one canal. The root surfaces of each tooth were examined under a stereomicroscope at 20X magnification for signs of crack lines, open apices, or anatomical anomalies, which should be eliminated if any of these features were present. Teeth with an initial canal size corresponding to a #15 K-file were included in the study. The specimens were stored in purified water for three months throughout the study.

Sample Preparation

For standardization purposes, the selected 60 teeth were measured from the apex toward the cementoenamel junction (CEJ), and each root was sectioned at 14 mm from the apex perpendicular to its long axis using a diamond disc under water cooling (14).

With waterproof 320-grit silicon carbide abrasive paper, 1 mm of each tooth's apical section was ground perpendicular to the tooth axis. Waterproof silicon carbide abrasive paper with grits of 1000 and 1200 was used to polish the apical surface in order to minimize small scratches and produce a sharp, greatly enlarged image.

Acrylic blocks were constructed with dimensions of 10×20 mm. The coronal 1 mm of each root remained uncovered, while the apical 2 mm were exposed to allow for intraoperative image acquisition, as described in a previous study (15).

To avoid dehydration, the exposed apical section of the root was submerged in water during instrumentation (16). Humidity was maintained during all procedures by immersing the roots in water.

A baseline image of the apical surface of each specimen was examined using a stereomicroscope (45X), and photographs were documented. In order to ensure standardization, all root canal preparations were performed using the EdgeFile X7 system (EdgeEndo®, USA). The instrumentation protocol

began with a #17/04 file in one or more passes, alternating with smaller hand files as needed, until the working length was reached. This was followed by passive use of #25/04 and #30/04 files to the full working length.

A new file was used for each tooth in instrumentation and retreatment step to ensure cutting efficiency and prevent any influence of instrument fatigue.

The canals were irrigated with 2 mL 2.5% sodium hypochlorite (NaOCl) between each file size. Irrigation was performed using a 27-gauge side-vented needle and syringe. After completion of the preparation, the canals were irrigated with 5 mL 17% EDTA for 1 minute and subsequently washed with 5 mL distilled water. After preparation, photographs of the apical regions of roots were obtained, and crack initiation was verified through stereo microscope, and the specimens showing evidence of visible cracks were uniformly distributed among the experimental groups.

Root Canal Obturation

Root canals were obturated using the single cone technique with AH Plus sealer and a size 30/.04 gutta-percha master cone (Dentsply, Germany). Samples were stored at 37°C with 100% humidity for two weeks to ensure complete sealer setting (Sure Dent, Korea).

Samples Grouping

1. Crack formation and propagation

Sixty samples were randomly divided into four experimental groups (n=15) G power analysis were performed.

- Group 1: Control group
- Group 2: Endostar RE Endo Retreatment
- Group 3: MANI GPR Retreatment
- Group 4: XP-endo Retreatment

2. Percent volume remanent of filling material

The last three group (without control group).

Evaluation of the Amount of Obturation Filling Material Using Cone Beam Computed Tomography Prior to Endodontic Retreatment

The provisional filling was removed from each specimen. Acrylic resin was then removed from all obturated teeth, which were subsequently embedded in a U-shaped dental wax rim for CBCT evaluation. CBCT imaging was performed using Vatech equipment in high-resolution dental mode (90 kV, 10.0 mA). The total scan time was 15 seconds. Furthermore, Each scan had a voxel size of 0.120 mm. The images were reviewed using EZ3D-I software. The volume of the "root filling material" was calculated using the volume measurement tool in the EZ3D-I software by defining the minimum and maximum intensity thresholds (17–19).

Experimental Groups and Retreatment Procedures

Group 1: Control (n=15 teeth)

Group 2: Endostar RE Endo (n=15 teeth)

Instruments used: File 2 (30/.08) and File 4 (30/.04), as per the manufacturer's instructions.

Group 3: MANI GPR (n=15 teeth)

From crown to middle portion of the canal, 2S #50 file was selected. From middle to apical, 4N #30 file was selected. Set a rubber stopper length of 1–2mm up to the apex. The files were moved in pull-stroke motion to remove the debris.

Group 4: XP-endo Retreatment (n=15 teeth)

The procedure followed the manufacturer's guidelines at 37°C to enable phase transformation. DR1 (30/.10) was used in the coronal third, followed by XP-endo Shaper (30/.04) to reach working length, and XP-endo Finisher R for final cleaning.

During the removal of root filling materials, the root canals were irrigated with 2 ml of a 2.5% sodium hypochlorite irrigation solution following the use of each file. After that, the XP-endo Finisher R (30/00) was employed; this file was utilized (for 1 minute) with slow and longitudinal movements to full length of the canal then the canal was irrigated with 1ml 2.5 % NaoCl (10).

Assessment of Crack Formation and Propagation

Photographs were captured of each tooth across all experimental groups following the retreatment procedure. The photos were obtained at 45X magnification utilizing a digital camera Nikon (Tokyo, Japan) connected to a stereo-microscope (MEIJI Techno).

The cracks were classified as follows:

- 1-crack: a single visible line extending from the root canal wall toward the outer surface without reaching it.
- 2-crack: two distinct crack lines observed.
- 1-crack Propagation: an increase in the length of a pre-existing crack observed in sequential imaging.
- 2-crack Propagation: two distinct crack propagation.

A scoring system was applied to categorize the severity and extent of crack formation and propagation based on stereomicroscopic images at each treatment stage.

Each specimen in the experimental groups had four photos (baseline, post-preparation, post-filling, post-retreatment). Each image was compared with the preceding one, and any detectable crack line on the apical surface that was absent in the prior image would be classified as a crack. Any increase in crack length from the preceding step is defined as crack propagation.as showed in Figures 1-3.

Amount of Gutta-percha Residual After Retreatment Procedure Using Cone Beam Computed Tomography

Following the removal of obturation material from the teeth, CBCT images were acquired as previously stated. The volume of the residual obturating material was evaluated as showed in Figures 4-6. The percentage of residual volume of obturating material was measured.

Statistical Analysis

Statistical analysis was performed using SPSS version 22. Descriptive statistics included mean, standard deviation (SD), standard error (SE), and range. Data normality was verified us-

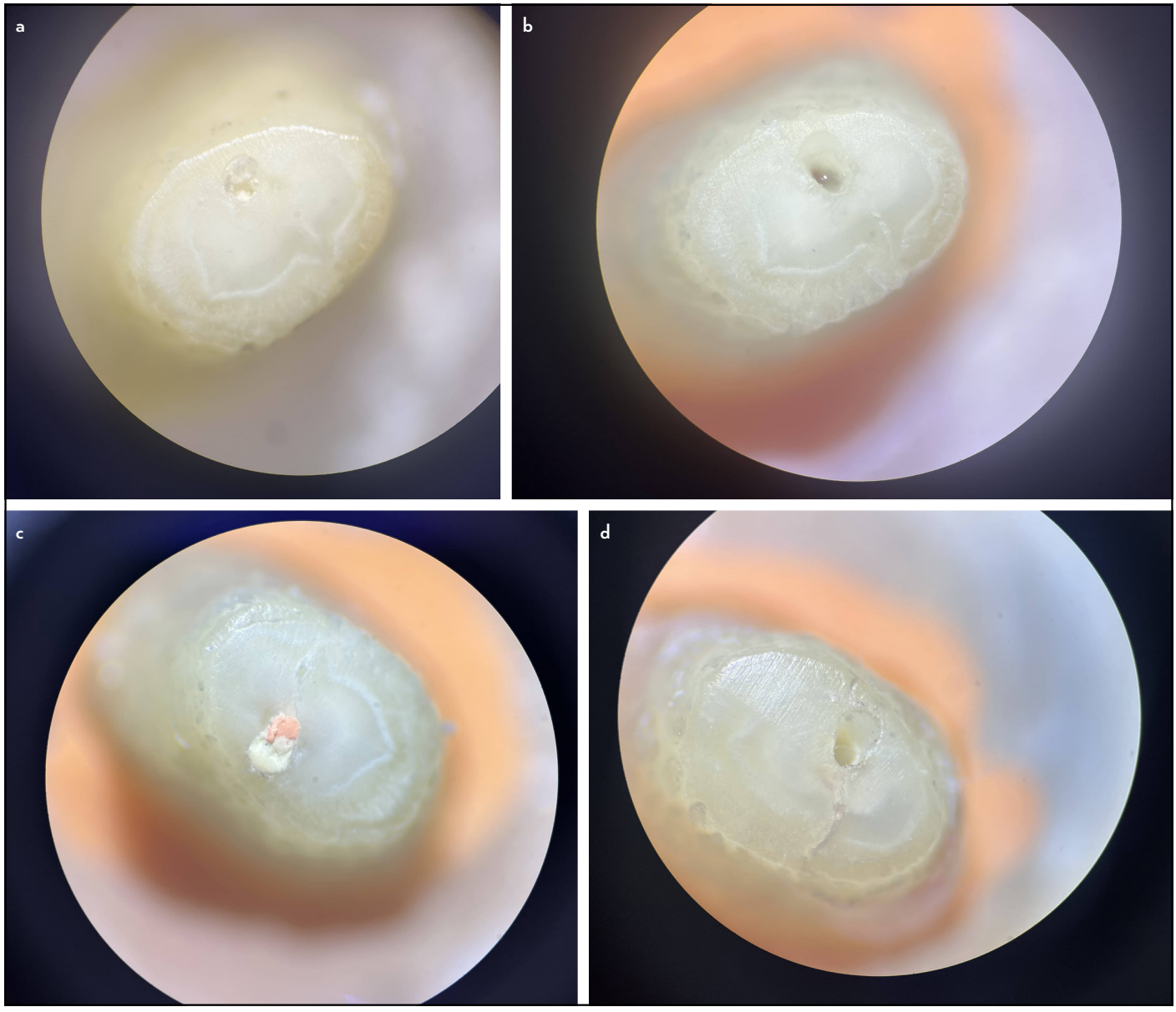

Figure 1. Image taking at 45X in stereoscope , (a) basal line image, (b) after instrumentation, (c) after obturation, (d) after retreatment with endostar retreatment system.

ing the Shapiro–Wilk test, and homogeneity of variances was assessed using Levene's test. For comparing the percentage of residual filling materials among groups, a one-way analysis of variance (ANOVA) was conducted, followed by Tukey's HSD post hoc test to identify pairwise differences. The incidence and propagation of cracks were analyzed using Fisher's exact test. A significance level of $p<0.05$ was used for all tests.

RESULTS

1. Crack Formation and Propagation After Retreatment

The incidence and propagation of dentinal cracks following retreatment were evaluated under a stereomicroscope at 45X magnification. Table 1 and Figure 7 provide detailed distributions for each group.

The XP-endo Retreatment group exhibited the lowest incidence of crack formation and propagation. Only 1 specimen (6.67%) showed a new crack, and 1 specimen (6.67%) showed crack propagation. In contrast, the Endostar RE Endo group had the highest occurrence of cracks, with 6 out of 15 samples (40%) exhibiting new cracks and 4 out of 15 samples (26.67%) demonstrating propagation. The MANI GPR group recorded intermediate values, with 3 samples (20%) showing new cracks and 1 sample (6.67%) showing propagation.

The statistical analysis using Fisher's exact test showed a significant difference between the XP and Endostar groups ($p=0.028$), indicating a lower incidence of cracks with the XP-endo system. No significant differences were observed between the Endostar and GPR systems ($p=0.166$) or between XP and GPR ($p=0.793$).

2. Percentage of Residual Root Filling Material

Descriptive statistics for the percentage of residual filling material are summarized in Table 2. The XP-endo Retreatment

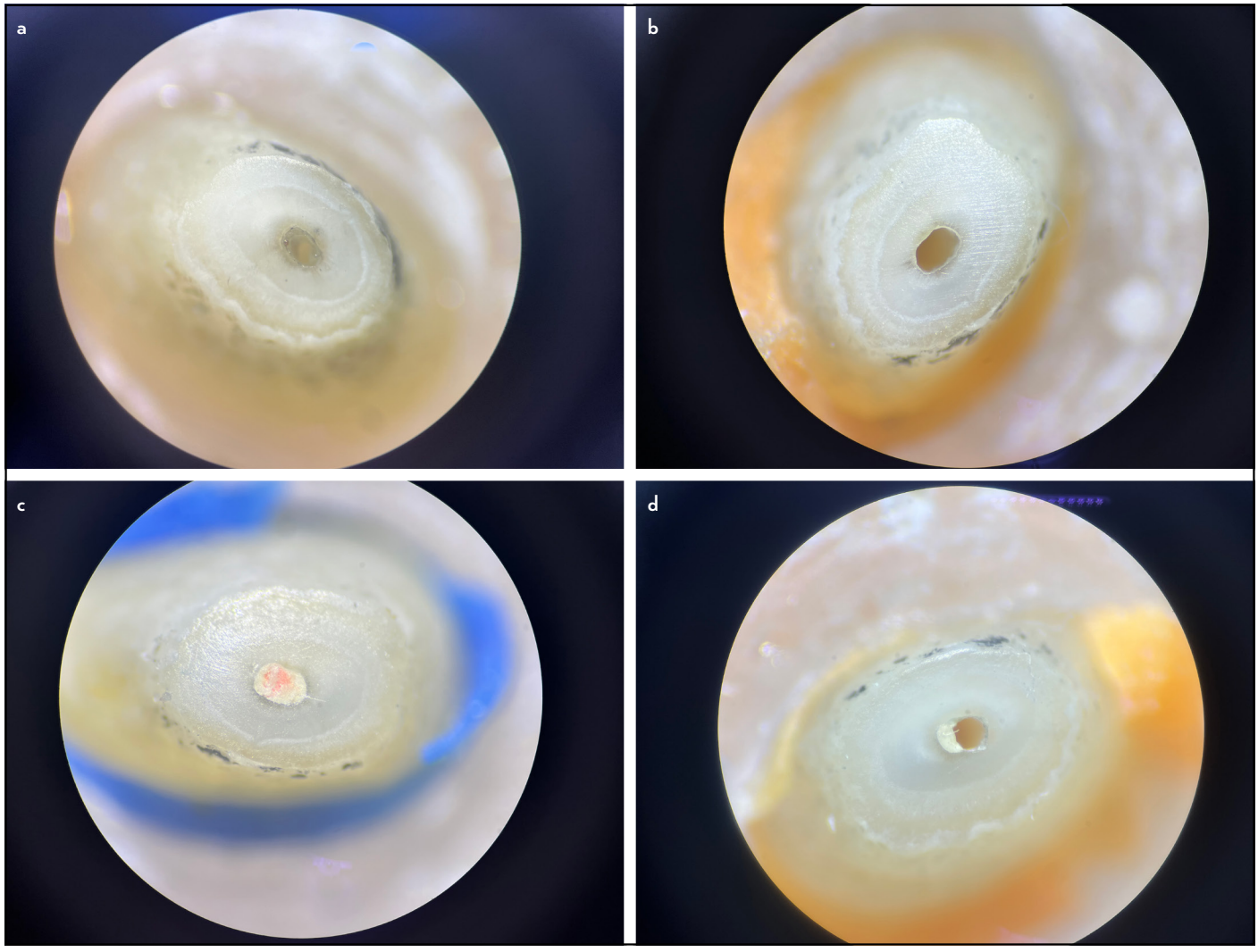

Figure 2. Image taking at 45X in stereoscope, (a) basal line image, (b) after instrumentation, (c) after obturation, (d) after retreatment with MANI GPR retreatment system.

MANI GPR: MANI gutta percha removal system.

group had the lowest mean residual volume (39.08% ± 2.93), followed by the MANI GPR group (44.51% ± 7.11), and the Endostar group with the highest residual volume (51.97% ± 9.26).

Shapiro wilk test used and percentage of residual filling material among groups was normally distributed ranged between 0.252 and 0.702.

Regarding homogeneity of variance , the variance for all groups was homogenous based on Levene's test, (F=3.084), (p=0.056).

A one-way ANOVA revealed a statistically significant difference among the three groups (F=13.02, p<0.01), as shown in Table 3. Post hoc Tukey HSD testing (Table 4) identified a significant difference between the Endostar and XP groups (p<0.001). However, differences between Endostar and GPR (p=0.058) and between GPR and XP (p=0.094) were not statistically significant.

These findings indicate that the XP-endo Retreatment system was more effective in removing root canal filling materials and caused significantly fewer dentinal cracks compared to the Endostar system.

DISCUSSION

Process retreatment may result in the development of crack lines and microcracks as well as harm to the tooth's remaining structure. Endodontic therapy may fail as a result of these crack lines and microcracks spreading in response to stress, such as that caused by occlusal pressures and restorative or endodontic procedures, and developing root fractures (3, 12).

The effective removal of root filling materials is an essential aspect of the retreatment process, as it allows access to necrotic tissue and bacteria-containing spaces that could be responsible for endodontic failure (20, 21). Many previous studies showed no technique was able to eliminate it completely (22–26).

Oval-shaped canals represent a problem for removing of all intracanal filling materials due to limited contact between the endodontic file and the root canal wall (27).

In this study, a consistent apical size of #30 was maintained for all instruments during retreatment to eliminate the influence of increasing the size of the retreatment file compared to

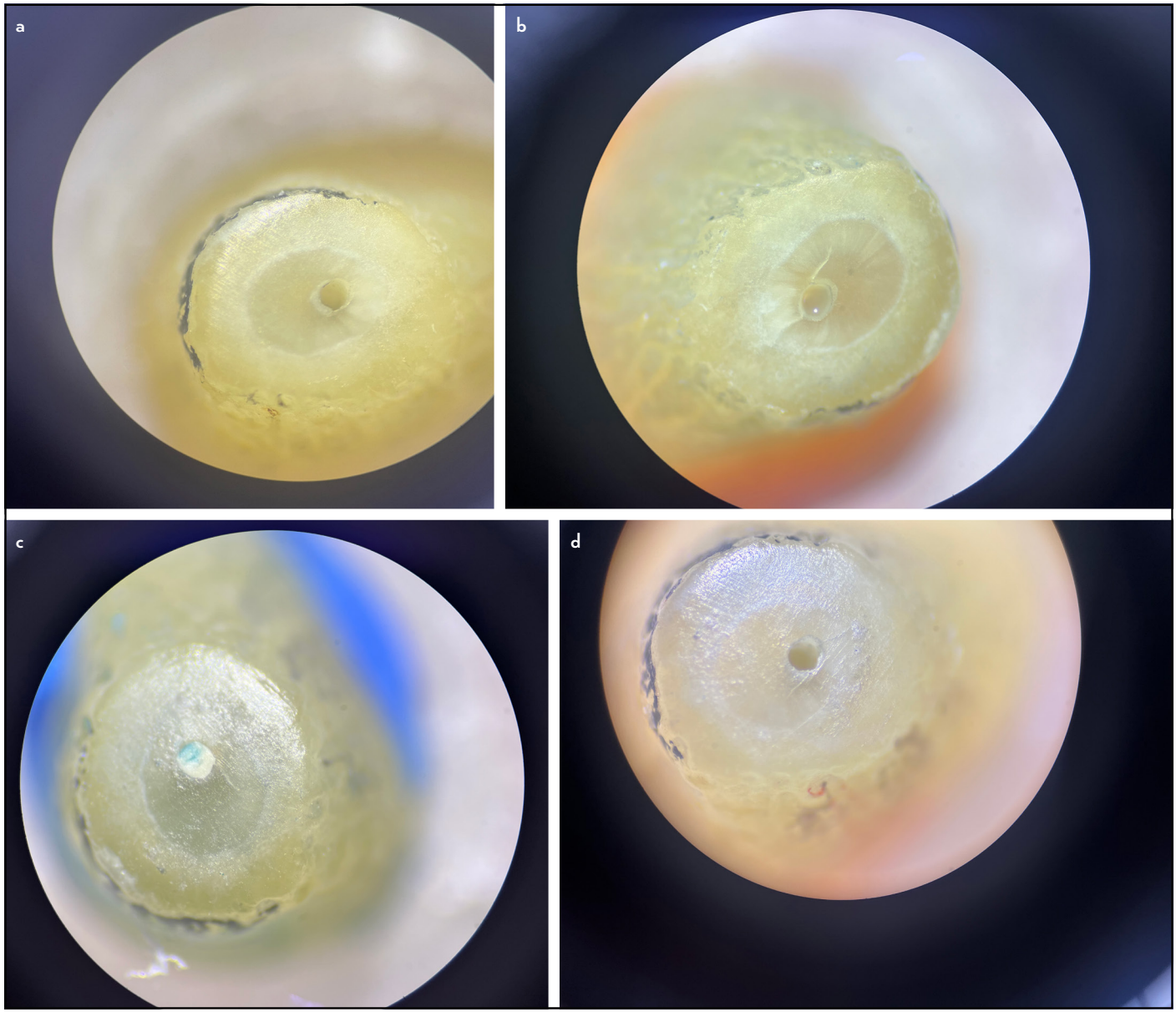

Figure 3. Image taking at 45X in stereoscope, (a) basal line image, (b) after instrumentation, (c) after obturation, (d) after retreatment with xp retreatment system.

the last file used for instrumentation, and to allow for uniform comparison between the various retreatment file systems.

After each step we take picture for the image in stereo-microscope to compare with baseline image to know there is new crack or its crack from the previous step and propagation happened.

In this study, AH Plus sealer was used because it is widely regarded as the gold standard among endodontic sealers due to its excellent physicochemical properties (12, 13).

The use of instrumentation techniques without solvent in retreatment is more effective and easier than using of solvent The material's structure may become viscous and highly adhesive, leading to the formation of softened gutta-percha films on the root canal surface (8, 28).

Cone beam computed tomography was employed to assess the volume of residual filling materials. The accurate determination of the precise location and volume of residual filling material is crucial during retreatment procedures (29).

A significant difference was observed between the XP and Endostar groups; therefore, the null hypothesis was rejected.

This study findings indicate that retreatment with the XP retreatment system resulted in the lowest dentinal defects in the apical region when compared to the same taper of the Endostar retreatment file. This outcome can be attributed to the XP-endo file's high flexibility, zero tapers, and NiTi MaxWire technology. It will be capable of navigating every corner and wall of the root canal with reduced stress on the canal wall, effectively removing debris left inside without deviating from the natural path of the root canal (10, 30, 31).

The GPR retreatment group generates and propagates fewer microcracks and exhibits lower residual remanent compared

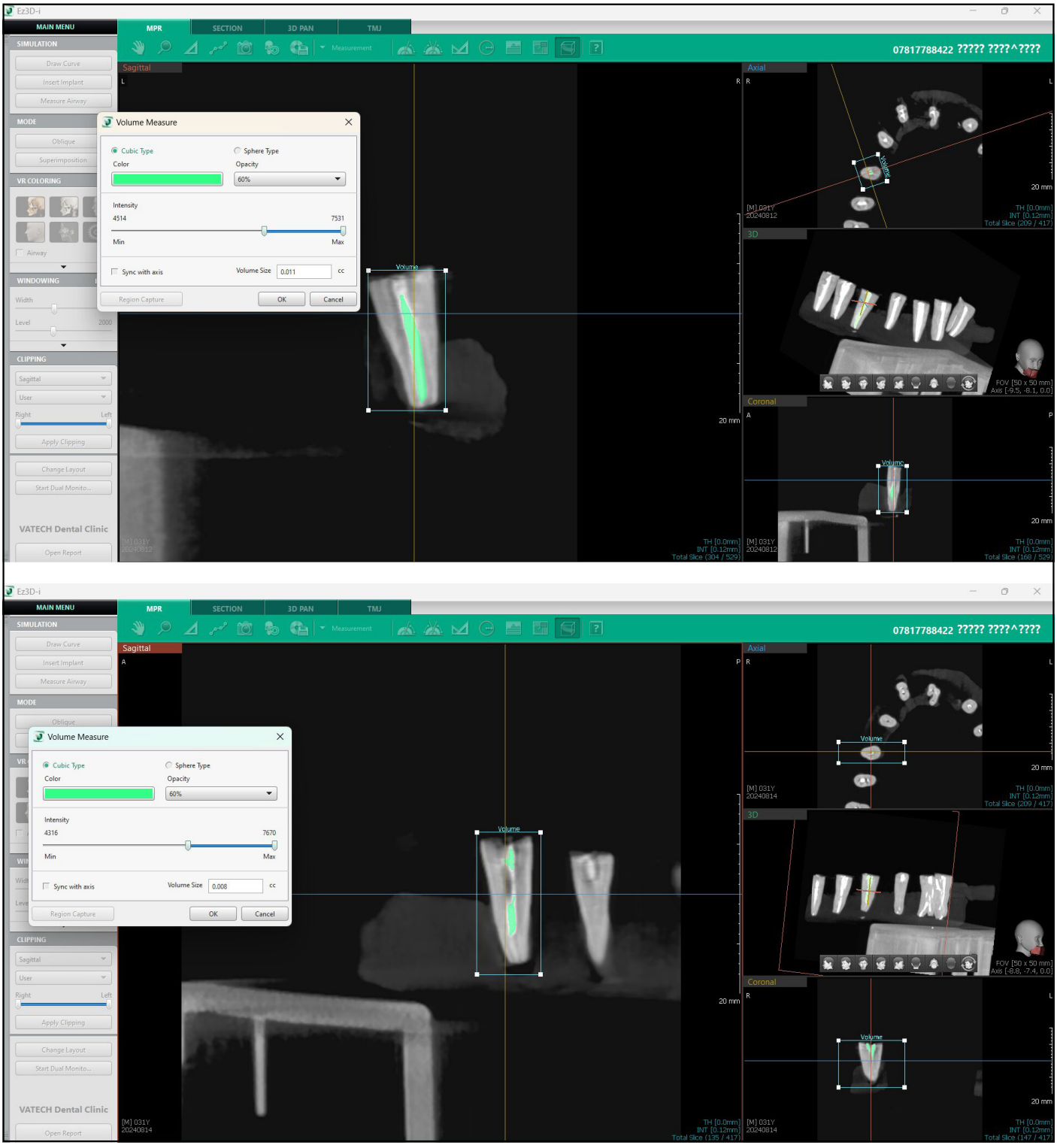

Figure 4. CBCT before and after retreatment with endostar RE endo retreatment system for assessment of residual volume remanent.

CBCT: Cone-beam computed tomography.

to the RE Endo retreatment group. The observed phenomenon may be attributed to the S type blade of the RE Endo files, characterized by two cutting edges, further enhances cutting efficiency. This increase in cutting edges correlates with heightened stress on the canal wall and a increase incidence of crack formation, and this design causes the gutta-percha to be cut in a circular cross-section. In contrast, the GPR system, with its low cutting efficiency and high speed, generates heat that plasticizes the gutta-percha, allowing it to accumulate in the flutes and be removed in bulk (32, 33).

The K type files exhibited four cutting edges with tapers of 8%, representing the highest taper (34) when compared to GPR files, which maintain a constant taper. This increases the contact area and elevates stress on the root canal wall, resulting in a higher incidence of crack formation and propagation (32).

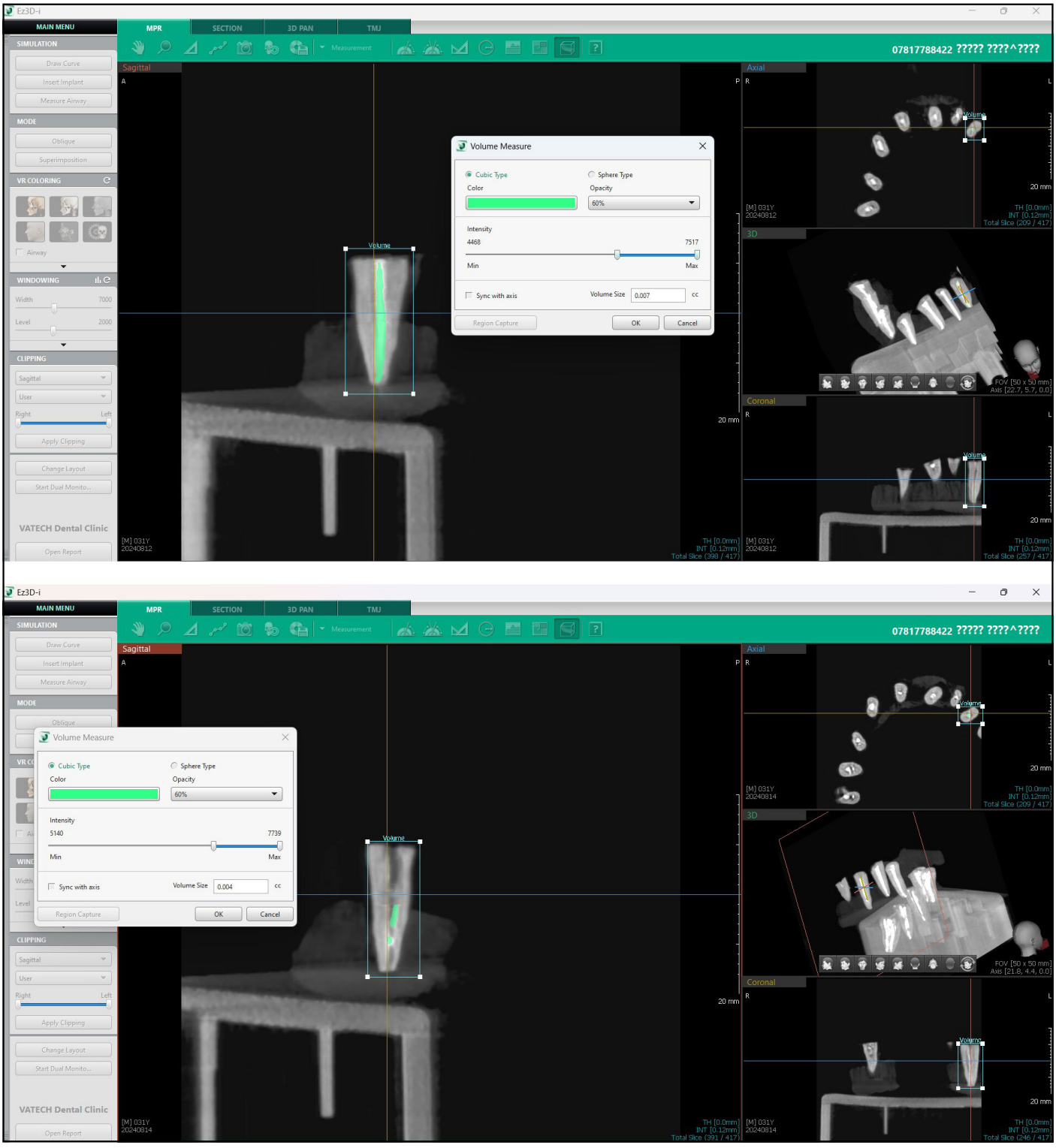

Figure 5. CBCT before and after retreatment with MANI GPR retreatment system for assessment of residual volume remanent.

CBCT: Cone-beam computed tomography, MANI GPR: MANI gutta percha removal system.

The XP-endo Retreatment system, which incorporates the DR1 file with its active tip design, facilitates efficient and rapid penetration of gutta-percha (GP) (35). The XP-endo shaper features a slim profile, a narrow taper, and a booster tip. This design, combined with GP plasticization at high rotational speeds, may facilitate the removal of gutta-percha (36). The mechanical action of the XP-endo Finisher R can enhance the dislodgement of residual materials, potentially leading to a more rapid removal of root filling materials (31).

Moreover, the XP-endo Finisher R — the final file in this system — features an innovative MaxWire alloy and a non-tapered design, which allow it to expand at body temperature and adapt more effectively to the canal walls, and as a result, during instrument motion the resistance exerted by canal anatomy

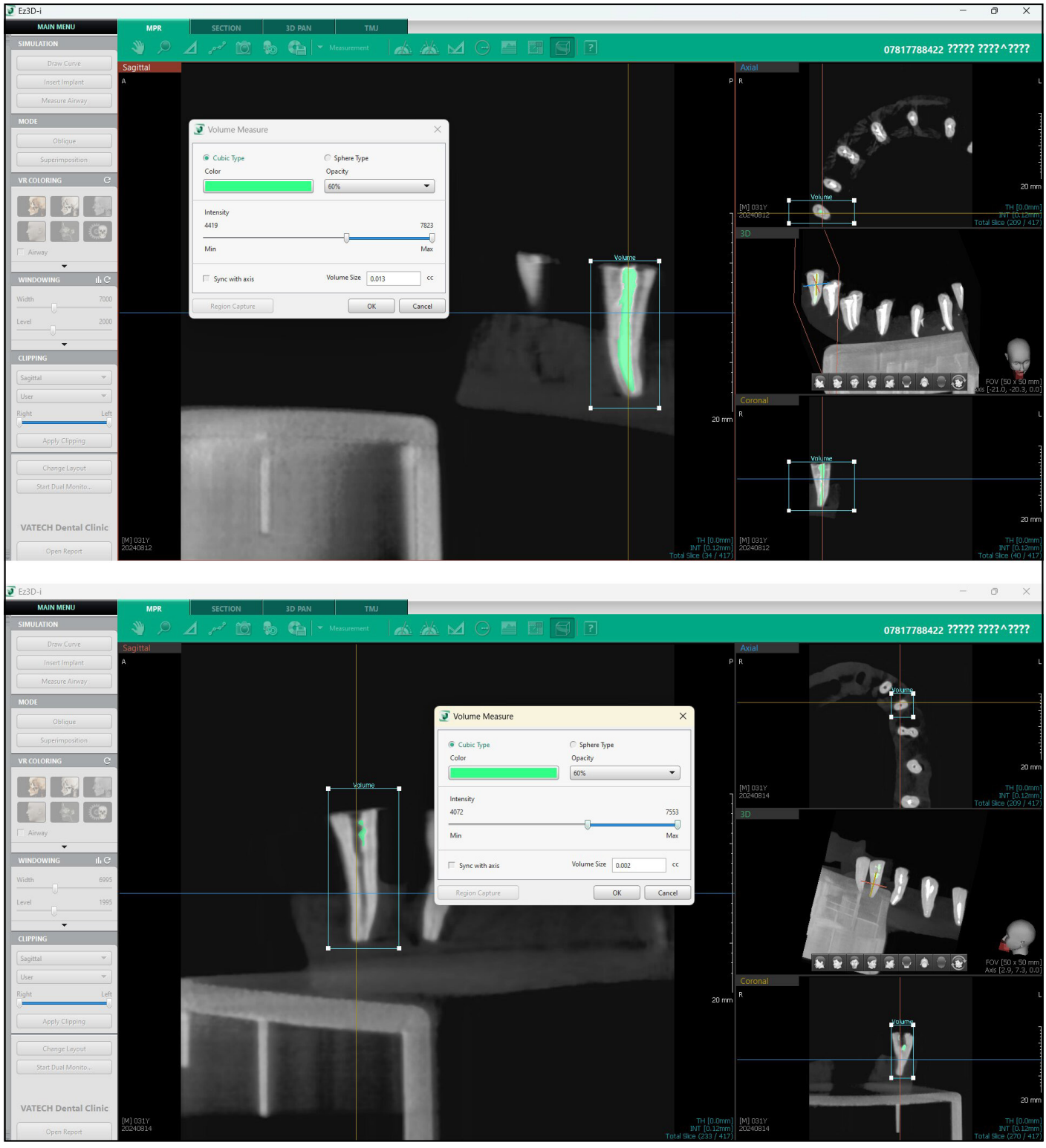

Figure 6. CBCT before and after retreatment with XP endo retreatment system for assessment of residual volume remanent.

CBCT: Cone-beam computed tomography.

compresses the elliptical portion of the instrument. Consequently, the tip of file is pressed against the canal walls. Instrument expansion within the canal may enable the semiactive tip of the file to engage and dislodge obturating root materials from the canal walls, which can subsequently be removed during canal irrigation (31). This result is consistent with previous studies reported by (10, 31, 37, 38).

XP-endo Shaper was associated with significantly more cases with complete filling removal due to its design that surround the gutta percha and withdrawal as one peice.

Clinical Implications

The choice of retreatment file can have a critical impact on both the effectiveness of the procedure and the long-term

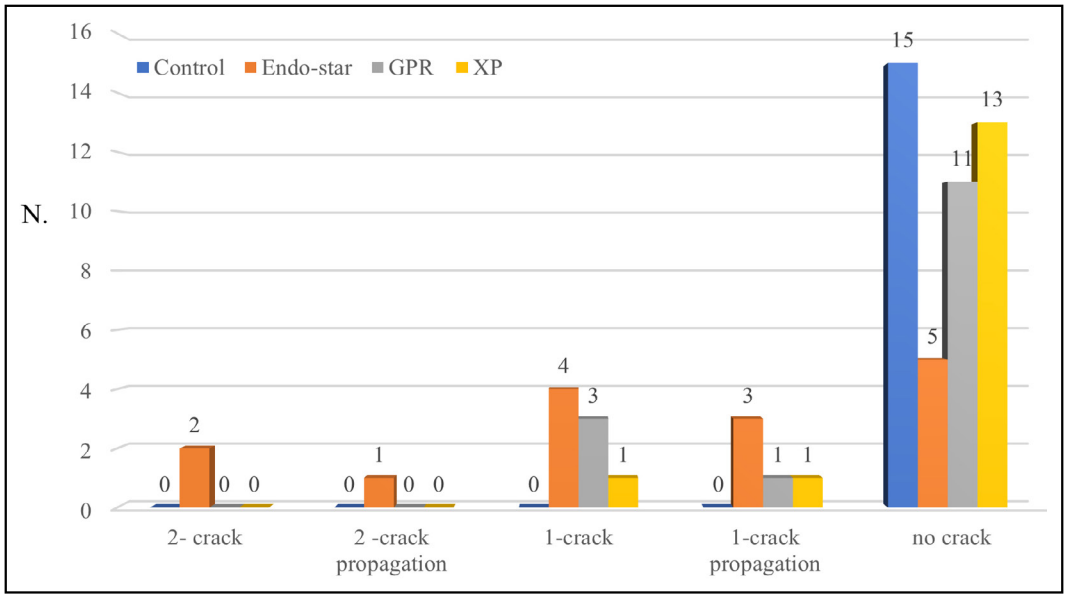

Figure 7. Bar chart for distribution of crack formation and propagation.
GPR: Gutta-percha removal.

TABLE 1. Distribution of crack formation and propagation

	Control		Endo-star		GPR		XP		Total		Fisher exact p value
	n	%	n	%	n	%	n	%	n	%	
2- crack	0	0.00	2	13.33	0	0.00	0	0.00	2	3.33	0.006 Sig.
2 -crack propagation	0	0.00	1	6.67	0	0.00	0	0.00	1	1.67	
1-crack	0	0.00	4	26.67	3	20.00	1	6.67	8	13.33	
1-crack propagation	0	0.00	3	20.00	1	6.67	1	6.67	5	8.33	
No crack	15	100.00	5	33.33	11	73.33	13	86.67	44	73.33	
					Endo-star X GPR						0.166 NS
					Endo-star X XP						0.028 Sig.
					XP X GPR						0.793 NS

p≤0.05 Significant (S) p>0.05. n: Number, GPR: Gutta-percha removal, Sig.: Significant, NS: Non-significant

TABLE 2. Descriptive statistic of percentage of residual filling material

Groups	n	Mean	±SD	±SE	Min	Max
Endo-star	15	51.973	9.259	2.391	39.500	69.200
GPR	15	44.507	7.106	1.835	35.300	55.500
XP	15	39.079	2.932	0.757	34.700	45.300

n: Number, SD: Standard deviation, SE: Standard error, Min: Minimum, Max: Maximum, GPR: gutta-percha removal

TABLE 3. ANOVA test of percentage of residual filling material among groups

	Sum of squares	df	Mean square	F	p
Between groups	1257.311	2	628.656	13.023	**<0.01**
Within groups	2027.492	42	48.274		
Total	3284.804	44			

ANOVA: Analysis of variance, df: Degrees of freedom, F: F-statistic

TABLE 4. Tukey HSD of percentage of residual filling material among groups

(I) Groups	(J) Groups	Mean difference	p
Endo-star	GPR	7.467	0.058 NS
	XP	12.894	<0.001 Sig.
GPR	XP	5.427	0.094 NS

HSD: Honest significant difference, GPR: Gutta-percha removal, NS: Non-significant, Sig.: Significant

prognosis of the treated tooth. The XP-endo system's minimal crack propagation and superior cleaning efficacy suggest it may be preferable, especially in teeth with thin dentinal walls or those at risk of vertical root fractures.

This study has several limitations. First, it was conducted *ex vivo*, which does not fully replicate intraoral conditions such as thermal variations, periodontal ligament simulation, or masticatory forces. Second, all specimens were standardized to a uniform root length and canal size, which may not reflect natural

anatomical variability encountered in clinical practice. Third, procedures were performed by a single operator, eliminating operator variability but potentially introducing performance bias. Fourthly, the crack observation method used (stereomicroscope) is limited in its ability to detect subsurface micro-cracks.

This technique is only effective for identifying surface cracks. More advanced, non-destructive 3D imaging techniques like micro-computed tomography (micro-CT) are superior for revealing these hidden defects.Future studies should include a larger sample size, a multi-operator design, and dynamic simulation of clinical conditions to further validate and expand on these findings.

CONCLUSION

No system exhibited a zero incidence of crack formation, nor was there a system capable of completely removing obturated materials. The XP-endo Retreatment system exhibited the lowest incidence of crack formation and propagation, demonstrating superior efficacy in the removal of gutta-percha and sealer, followed by the MANI GPR system and the Endostar retreatment system.

Disclosures

Ethics Committee Approval: The study was approved by the Mustansiriyah University Ethics Committee (no: MUOPR29, date: 01/05/2023).

Informed Consent: Informed consent was obtained from all participants.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study received no financial support.

Use of AI for Writing Assistance: The authors declared that no artificial intelligence (AI)-assisted technologies, such as Large Language Models (LLMs), chatbots, or image creators, were used in the production of this manuscript.

Authorship Contributions: Concept – A.M.W., B.M.Z.; Design – B.M.Z.; Supervision – M.Y.A.; Materials – M.Y.A.; Data collection and/or processing – A.M.W., B.M.Z.; Data analysis and/or interpretation – A.M.W., M.Y.A.; Literature search – M.Y.A.; Writing – A.M.W.; Critical review – B.M.Z.

Peer-review: Externally peer-reviewed.

REFERENCES

1. Sun X, Yang Z, Nie Y, Hou B. Microbial Communities in the Extraradicular and Intraradicular Infections Associated With Persistent Apical Periodontitis. Front Cell Infect Microbiol 2021; 11:798367. [Crossref]
2. Nasiri K, Wrbas KT. Comparison of the efficacy of different Ni-Ti instruments in the removal of gutta-percha and sealer in root canal retreatment. Indian J Dent Res 2020; 31(4):579–84. [Crossref]
3. Çitak M, Özyürek T. Effect of different nickel-titanium rotary files on dentinal crack formation during retreatment procedure. J Dent Res Dent Clin Dent Prospects 2017 ;11(2):90–5. [Crossref]
4. Cassimiro M, Romeiro K, Gominho L, de Almeida A, Silva L, Albuquerque D. Effects of Reciproc, ProTaper Next and WaveOne Gold on Root Canal Walls: A Stereomicroscope Analysis. Iran Endod J 2018; 13(2):228–33.
5. Jamal SF, Talabani RM. Influence of Different Glide Path Techniques on Microcrack Formation after Two Different Root Canal Preparation Treatments: Micro Computed Tomography Analysis. Eur Endod J 2024; 9(2):124–32. [Crossref]
6. Aboud LRdL, Santos BCd, Lopes RT, Viana LAC, Scelza MFZ. Effect of aging on dentinal crack formation after treatment and retreatment procedures: a micro-CT study. Braz Dent J 2018; 29:530–5. [Crossref]
7. Yilmaz A, Helvacioglu-Yigit D, Gur C, Ersev H, Kiziltas Sendur G, et al. Evaluation of Dentin Defect Formation during Retreatment with Hand and Rotary Instruments: A Micro-CT Study. Scanning. 2017; 2017:4868603. [Crossref]
8. Dotto L, Sarkis-Onofre R, Bacchi A, Pereira GKR. The use of solvents for gutta-percha dissolution/removal during endodontic retreatments: A scoping review. J Biomed Mater Res B Appl Biomater 2021; 109(6):890–901. [Crossref]
9. Kiraz G, Kaya BÜ, Ocak M, Uzuner MB, Çelik HH. Micro-CT evaluation of the removal of root fillings using rotary and reciprocating systems supplemented by XP-Endo Finisher, the Self-Adjusting File, or Er,Cr:YSGG laser. Restor Dent Endod. 2023 ;48(4):e36. [Crossref]
10. Machado AG, Guilherme BPS, Provenzano JC, Marceliano-Alves MF, Gonçalves LS, Siqueira JF Jr, Neves MAS. Effects of preparation with the Self-Adjusting File, TRUShape and XP-endo Shaper systems, and a supplementary step with XP-endo Finisher R on filling material removal during retreatment of mandibular molar canals. Int Endod J 2019; 52(5):709–15. [Crossref]
11. Bernardes RA, Duarte MAH, Vivan RR, Alcalde MP, Vasconcelos BC, Bramante CM. Comparison of three retreatment techniques with ultrasonic activation in flattened canals using micro-computed tomography and scanning electron microscopy. Int Endod J 2016; 49(9):890–7. [Crossref]
12. Tejaswi S, Singh A, Manglekar S, Ambikathanaya UK, Shetty S. Evaluation of dentinal crack propagation, amount of gutta percha remaining and time required during removal of gutta percha using two different rotary instruments and hand instruments - An *In vitro* study. Niger J Clin Pract. 2022; 25(4):524–30. [Crossref]
13. Crozeta BM, Lopes FC, Menezes Silva R, Silva-Sousa YTC, Moretti LF, Sousa-Neto MD. Retreatability of BC Sealer and AH Plus root canal sealers using new supplementary instrumentation protocol during non-surgical endodontic retreatment. Clin Oral Investig 202; 25(3):891–9. [Crossref]
14. Kim H, Kim E, Lee SJ, Shin SJ. Comparisons of the Retreatment Efficacy of Calcium Silicate and Epoxy Resin-based Sealers and Residual Sealer in Dentinal Tubules. J Endod 2015; 41(12):2025–30. [Crossref]
15. Adorno CG, Yoshioka T, Jindan P, Kobayashi C, Suda H. The effect of endodontic procedures on apical crack initiation and propagation *ex vivo*. Int Endod J 2013; 46(8):763–8. [Crossref]
16. Liu R, Kaiwar A, Shemesh H, Wesselink PR, Hou B, Wu MK. Incidence of apical root cracks and apical dentinal detachments after canal preparation with hand and rotary files at different instrumentation lengths. J Endod 2013; 39(1):129–32. [Crossref]
17. Madani ZS, Simdar N, Moudi E, Bijani A. CBCT Evaluation of the Root Canal Filling Removal Using D-RaCe, ProTaper Retreatment Kit and Hand Files in curved canals. Iran Endod J 2015; 10(1):69–74.
18. Madarati AA, Al-Nazzawi AA, Sammani AMN, Alkayyal MA. The efficacy of retreatment and new reciprocating systems in removing a gutta-percha-based filling material. J Taibah Univ Med Sci 2018; 13(5):452–8. [Crossref]
19. Prasad A, Nair RS, Angelo JMC, Mathai V, Vineet R, Christopher SR. A comparative evaluation of retrievability of Guttapercha, Resilon and CPoints for retreatment, using two different rotary retrieval systems-An *ex vivo* study. Saudi Endod J 2018; 8(2):87–92. [Crossref]
20. Jain M, Singhal A, Gurtu A, Vinayak V. Influence of Ultrasonic Irrigation and Chloroform on Cleanliness of Dentinal Tubules During Endodontic Retreatment-An *Invitro* SEM Study. J Clin Diagn Res 2015; 9(5):ZC11–5. [Crossref]
21. Yürüker S, Görduysus M, Küçükkaya S, Uzunoğlu E, Ilgın C, Gülen O, et al. Efficacy of Combined Use of Different Nickel-Titanium Files on Removing Root Canal Filling Materials. J Endod 2016; 42(3):487–92. [Crossref]
22. Zuolo AS, Mello JE Jr, Cunha RS, Zuolo ML, Bueno CE. Efficacy of reciprocating and rotary techniques for removing filling material during root canal retreatment. Int Endod J 2013; 46(10):947–53. [Crossref]
23. Rios Mde A, Villela AM, Cunha RS, Velasco RC, De Martin AS, Kato AS, et al. Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal. J Endod 2014; 40(4):543–6. [Crossref]
24. de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, Chu R, Cunha RS. Evaluation of the Efficacy of TRUShape and Reciproc File Systems in the Removal of Root Filling Material: An *Ex Vivo* Micro-Computed Tomographic Study. J Endod 2016; 42(2):315–9. [Crossref]
25. Nevares G, de Albuquerque DS, Freire LG, Romeiro K, Fogel HM, Dos Santos M, et al. Efficacy of ProTaper NEXT Compared with Reciproc in Removing Obturation Material from Severely Curved Root Canals: A Micro-Computed Tomography Study. J Endod 2016; 42(5):803–8. [Crossref]
26. Eid BM, Maksoud HBA, Elsewify TM. Efficacy of XP-endo Finisher-R in enhancing removal of bioceramic sealer from oval root canal: a micro-CT study. G Ital Endod 2021; 35(1).
27. Versiani MA, Leoni GB, Steier L, De-Deus G, Tassani S, Pécora JD, et al. Micro-computed tomography study of oval-shaped canals prepared with the self-adjusting file, Reciproc, WaveOne, and ProTaper universal systems. J Endod. 2013; 39(8):1060–6. [Crossref]

28. Bhagavaldas MC, Diwan A, Kusumvalli S, Pasha S, Devale M, Chava DC. Efficacy of two rotary retreatment systems in removing Gutta-percha and sealer during endodontic retreatment with or without solvent: A comparative *in vitro* study. J Conserv Dent 2017; 20(1):12–6. [Crossref]
29. Yilmaz F, Sönmez G, Kamburoğlu K, Koc C, Ocak M, Celik H. Accuracy of CBCT images in the volumetric assessment of residual root canal filling material: effect of voxel size. Niger J Clin Pract 2019; 22(8):1091–8. [Crossref]
30. Newase P, Bhargava K, Paunikar M, Bhawalkar A, Kumar T, Sarode G. Comparative evaluation of the effect of hand file, different nickel-titanium retreatment files, and self-adjusting file system on the incidence of dentinal microcrack formation during the removal of root canal filling material: An *in vitro* stereomicroscopic study. Med J DY Patil Vidyapeeth 2023; 16:670–8. [Crossref]
31. De-Deus G, Belladonna FG, Zuolo AS, Cavalcante DM, Carvalhal JCA, Simões-Carvalho M, et al. XP-endo Finisher R instrument optimizes the removal of root filling remnants in oval-shaped canals. Int Endod J 2019; 52(6):899–907. [Crossref]
32. Alberto Rubino G, de Miranda Candeiro GT, Gonzales Freire L, Faga Iglecias E, de Mello Lemos É, Luiz Caldeira C, et al. Micro-CT Evaluation of Gutta-Percha Removal by Two Retreatment Systems. Iran Endod J 2018; 13(2):221–7.
33. Jena A, Shashirekha G, Barai S, Mahaprasad A. Comparison of Apically Extruded Debris after Retreatment Procedure with ProTaper and Endostar Retreatment File Systems. JCDR 2018; 12(7). [Crossref]
34. Endo Star. Endostar RE Re Endo Rotary System. Avaliable at: https://www.endostar.eu/en/produkty/endostar-re-re-endo-rotary-system-en/ Accessed on Feb 23,2025.
35. Garg A, Nagpal A, Shetty S, Kumar S, Singh KK, Garg A. Comparison of Time Required by D-RaCe, R-Endo and Mtwo Instruments for Retreatment: An *in vitro* Study. J Clin Diagn Res 2015; 9(2):ZC47–9. [Crossref]
36. Azim AA, Piasecki L, da Silva Neto UX, Cruz ATG, Azim KA. XP Shaper, A Novel Adaptive Core Rotary Instrument: Micro-computed Tomographic Analysis of Its Shaping Abilities. J Endod 2017; 43(9):1532–8. [Crossref]
37. Kapasi K, Kesharani P, Kansara P, Patil D, Kansara T, Sheth S. *In vitro* comparative evaluation of efficiency of XP-endo shaper, XP-endo finisher, and XP-endo finisher-R files in terms of residual root filling material, preservation of root dentin, and time during retreatment procedures in oval canals - A cone-beam computed tomography analysis. J Conserv Dent 2020; 23(2):145–51. [Crossref]
38. Uzunoglu-Özyürek E, Küçükkaya Eren S, Karahan S. Contribution of XP-Endo files to the root canal filling removal: A systematic review and meta-analysis of *in vitro* studies. Aust Endod J 2021; 47(3):703–14. [Crossref]