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ORIGINAL ARTICLE

Efficacy of Various Heat-treated Retreatment File Systems on Dentin Removal and Crack Analysis: An *in vitro* Study

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ABSTRACT

Objective: To analyze the remaining dentin thickness and crack formation after retreatment, comparing three file systems. **Material and Methods:** Using a standard root length of 18 mm, forty-five single-rooted teeth were decoronated and obturated after being randomly divided into three groups. Solite RS3, Solite RS3 Black, and Solite RE Black retreatment file systems were employed to remove the gutta-percha following a nano-CT scan performed before preparation. A post-operative nano-CT scan was performed to determine the amount of dentin thickness and crack that remained, and both scans were superimposed. One-way ANOVA and subsequent post-hoc tests were employed to ascertain statistical significance for both intra-group and inter-group variations. **Results:** Solite RE Black removed lesser dentin compared to the other two retreatment file systems ($p<0.05$). There were no significant differences in crack formation amongst all retreatment file systems ($p>0.05$). **Conclusion:** Solite RE Black retreatment file system proved to have more dentin conservation and less crack propagation during retreatment. Excessive tooth structure loss can compromise the long-term success of endodontically treated teeth, increasing the risk of cracks and potential vertical root fractures.

Keywords: Diagnostic Imaging; Endodontics; Root Canal Therapy.

Introduction

Root canal treatment success rates vary widely based on multiple factors, including the quality of the procedure, patient-specific conditions, and follow-up care. The success of root canal treatment relies on several key elements: comprehensive canal cleaning to remove infected tissue and bacteria, thorough disinfection to eliminate microbes, and complete filling of the canal space to prevent reinfection. Success rates typically range from 50% to 90%, highlighting the importance of skilled execution and meticulous attention to detail in achieving favorable outcomes [1]. The primary goal of the retreatment procedure for root canal therapy is to eliminate all gutta-percha from the root canal. However, regardless of the retreatment approach, it is nearly impossible to remove all gutta-percha or sealer from root canals [2].

Numerous techniques, including the use of ultrasonic technology, heat-carrying tools, chemicals, endodontic hand files, and engine-driven rotary files, can be employed to remove obturating material from the root canal system. Hand files take longer to remove gutta-percha than engine-driven rotary systems [3]. Using a rotary device, there are several safe and effective ways to accomplish root canal retreatment, as it eliminates the gutta-percha (GP) more quickly [4].

Previous research revealed that due to varying stress levels produced by the files on the canal walls, a file's taper and design may have an impact on the occurrence of cracks [5]. NiTi rotary files resulted in dentinal defects like cracks during root canal shaping and retreatment treatments despite their many benefits [6]. Furthermore, it is possible to implement various file systems, with variable tapers, cutting blades, and differently arranged tips that utilize rotary, reciprocal, and manual movement [7].

The amount of dentin removed during endodontic treatment may cause dentinal cracks, and retreatment methods may cause these cracks to worsen into vertical root fractures, which could result in the loss of a tooth [8]. Within this framework, assessing dentinal microcracks following endodontic therapy is a new and significant subject that scientific data should guide to inform clinical practice and lessen this unfavorable circumstance.

NiTi rotary systems for root canal retreatment are made by several companies. This study used three different retreatment file systems: Solite RS3 retreatment files, Solite RS3 Black retreatment files, and Solite RE Black. The three-file systems with heat-treated technology were utilized in Solite RS3. Solite RE 2 is a two-file system that utilizes c wire technology, while Solite RE black combines C wire technology with a variable taper design.

Micro-computed tomography (micro-CT) imaging is valuable for assessing pre- and post-procedural defects within the same sample. It offers detailed 2- and 3-dimensional analysis of root canal morphology in a non-destructive manner. However, Nano-CT has demonstrated even higher spatial resolution capabilities, reaching up to 400 nanometers [9]. The principal goal of this study is to evaluate the effectiveness of different heat-treated retreatment file systems in preserving remaining dentin and identifying cracks in single-rooted teeth, utilizing nano-CT imaging.

Material and Methods

Ethical Clearance and Sample Size Calculation

The Saveetha Institutional Ethical Committee of Dental Sciences (SRB/SDC/ENDO-2106/23/080) approval was given before the start of the research. The sample size for this study was established through consideration of prior research [10]. After the assessment, a total sample size of 45 was determined, achieving a

power of 95% (1- β = 95%, α= 0.05). Specimens were randomly distributed into three groups (n=15) for experimentation.

Specimen Selection

Forty-five freshly extracted mandibular premolars with a single root and a single canal were gathered, and they were kept for 24 hours in a chloramine-T solution before being placed in regular saline to be employed in the investigation. The research excluded teeth with internal or exterior resorption, cavities, restorations, flaws, calcified canals, and faults.

Sample Preparation

All three groups were prepared by a single trained operator, excluding the possibility of inter-operator variability-related bias. Following decoronation at the cementoenamel junction, forty-five mandibular premolars were used, and the samples were standardized to 18 mm [11]. The instrument utilized was a standard endodontic access cavity preparation bur, size 2 (Dentsply Maillefer, Ballaigues, Switzerland). After the canal was found, it was cleaned and shaped. To clean the pulp chambers of any remaining material, a 30 gauge side-vented needle (Profit Dental, India) was used to irrigate normal saline solution. A size 10 K file measuring 21 mm (Mani Inc., Tochigi, Japan) was utilized to regularly assess the canal's patency.

Root Canal Preparation

Following the manufacturer's instructions, all specimens were prepared using rotary files up to size 15 K-file (Mani Inc., Tochigi, Japan). Coronal and apical portions were further shaped using a P0 rotary file until reaching PF2 6% taper or the working length, as per manufacturer instructions. A 15% solution of ethylenediaminetetraacetic acid (EDTA) (RC Help, Prime Dental Products Pvt Ltd, Thane, India) and a 5.25% sodium hypochlorite irrigant (Acquafarma Farmácia, Niteroi, RJ, Brazil) were used during the preparatory phase across all groups. The Profit S3 rotary file system (Profit Dental, India) was utilized following the manufacturer's prescribed protocol. When preparing the canal, irrigation was done following every change in file size. For obturation, 6% taper size 25 gutta-percha (DiaDent Group International, Burnaby, Canada) and AH Plus sealer (Dentsply Maillefer, Ballaigues, Switzerland) were used. A radiographic examination of a few teeth was conducted as a pilot to ensure obturation quality. Subsequently, all group samples were incubated at 37°C with distilled water to allow sealers to set before segmentation and imaging.

Nano-CT Scanning

A micro-CT (Bruker Belgium SA, Kontich, Belgium) utilized the SKYSCAN 2214 to obtain an ultra-precision scan of the prepared specimens. The imaging parameters used consisted of a 100kV voltage (10W and 100μA) and an exposure duration of 1100 ms. A 0.3° rotation step 360° revolving flat panel detector made image acquisition easier. NRecon v.1.6.9 software (Bruker Belgium SA, Kontich, Belgium) was used to reconstruct the pictures. The original grayscale images underwent several techniques to reduce noise. These techniques included applying a 0.50 post-alignment to address any acquisition misalignment, correcting for 10% beam hardening, performing 10% ring artifact correction, and using a Gaussian filter (Smoothing, kernel = 2).

Retreatment Procedures

A single operator operated a water bath machine, which held water at a temperature of 37°C, to carry out the retreatment procedure. In a water bath (GfL Gesellschaft für Luftverkehrsforschung mbH, Berlin, Germany), the irrigation solutions were also heated to 37°C. Three groups of 15 specimens each were formed by randomly assigning the forty-five teeth to the automated system (http://www.random.org). The groups are as described below:

- Group 1: Solite RS3

Continuous clockwise rotation of the instruments was achieved by gently pecking in and out at a speed of 350 rpm and a torque of 2.6 N/cm. Filling removal in the coronal third was done with instrument RS1 - 30/.08 (15mm), in the middle third with instrument RS2 - 25/.07 (18mm), and at the WL with instrument RS3 - 20.06 (23mm).

- Group 2: Solite RS3 Black

Continuous clockwise rotation of the instruments was achieved by gently pecking in and out at a speed of 350 rpm and a torque of 2.6 N/cm. Filling removal in the coronal third was done using instrument RS1 Black - 30/.08 (15mm), while the middle third, which is composed of c wire technology, was filled using instrument RS2 Black - 25/.07 (18mm), and the WL was filled with instrument RS3 Black - 20.06 (23mm).

- Group 3: Solite RE Black

In this retreatment file, both file systems have a variable taper. A mild in-and-out pecking motion with a rate of 350 rpm and a torque of 2.6 N/cm was employed to rotate the instruments continuously in a clockwise direction. Instrument RE1 - tip size 0.30 with variable taper used to remove coronal and middle third GP followed by instrument RE2 - tip size 0.20 with variable taper made up of c wire technology for GP removal in the middle and apical third of the canal.

In between each preparation phase, 2 mL of 5.25% NaOCl was used to irrigate using syringes that are disposable and a 30 gauge side vent needle (Profit Dental, India) was withdrawn 2 mm short of the working length, the removal of filling material was deemed complete without the use of a solvent [12,13]. The major steps involved in this study research have been highlighted in the PRILE 2021 [14] flowchart (Figure 1).

Post-operative Scan

Following the root canal retreatment, the residual root canal filling volume and apical transportation were assessed for each sample separately utilizing a SkyScan 1272 micro-CT system (Bruker Belgium SA, Kontich, Belgium). The imaging setup included a copper-aluminum filter, an isotropic voxel size of 11.88 mm, an x-ray voltage of 100 kV, an exposure time of 1475 milliseconds, a 360-degree rotation, and a rotation step of 0.3.

Imaging Reconstruction and Processing

To reconstruct the image, we utilized NRecon software (version 2.1.0.2, SkyScan, Kontich, Belgium). This software employed a distinctive approach to generate axial, two-dimensional images with a resolution of 1000 pixels. During the reconstruction process, the values for ring rectification and artifact reduction were maintained at 0 to guarantee that the original image data was altered as little as possible. The final images provided an exceptional three-dimensional depiction of the root canal architecture.

We used the CTAn Application (version 1.21.2.0, Skyscan, Aartselaar, Belgium) for 3D volumetric imaging and finished the root canal analysis after reconstructing the images. With the aid of this software, canal volumes may be inspected and measured, enabling a thorough evaluation of changes in canal morphology brought about by root canal preparation methods. The integration of NRecon and CTAn software enables precise and comprehensive three-dimensional visualization and assessment of the root canal architecture.

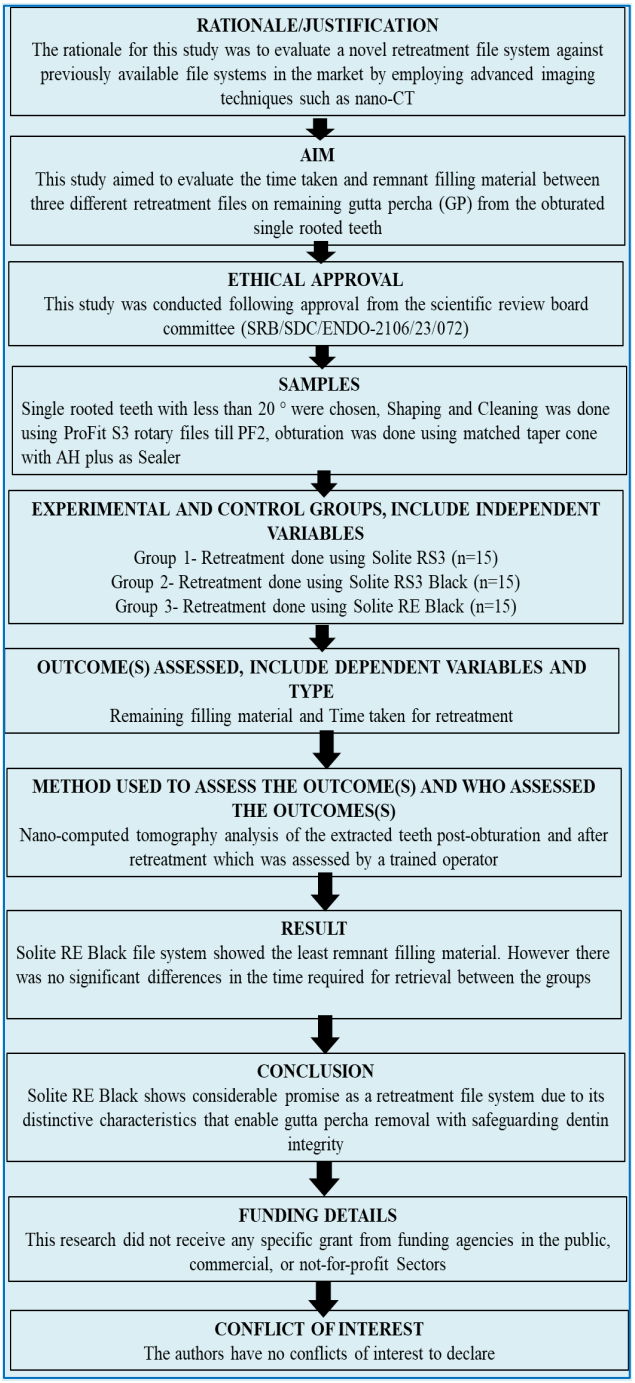

Figure 1. PRILE flow chart.

Evaluation of Remaining Dentin Thickness

The evaluator, who is skilled in analyzing the same, looked at the cross-section images of the premolar single roots to look for any fissures, the existence or absence of cracks, and the amount of dentin that remained.

Equal sections of the samples were separated into the coronal, medial, and apical regions. The formula used to calculate the percentage of dentin thickness that remained after retreatment was = MD1-MD2, m2+d2/2. The shortest distances between the mesial and distal edges of the root, respectively, and the related edges of the filled canal were represented by ml, d1, and the shortest distances between the mesial and distal edges of the root, respectively, were represented by m2, d2. Pre- and post-measurements for Solite RS3, Solite RS3 Black, and Solite RE Black were taken using Nano CT and noted down in an Excel sheet in order to calculate the remaining dentin thickness. The mean percentage volume of dentin removed was calculated using CT Vol software.

Microcrack Formation Evaluation

The Bruker MicroCT software, version 1.5.2.4, was utilized to import the micro-CT images and extract coronal, sagittal, and transaxial slices from each sample. Subsequently, three-dimensional images were generated. Two experienced endodontists examined a total of 1300 transverse cross-sectional nano-CT slices, one for each tooth, were inspected by two skilled endodontists. The post-instrumentation image was subjected to comparison and analysis with the corresponding pre-instrumentation cross-sectional image to confirm the existence of pre-existing microcracks or craze lines. Sectional images in three regions — the coronal, middle, and apical areas — each measuring five millimeters, four millimeters, and four millimeters in length, respectively, were used to assess the fracture distribution.

Statistical Analysis

Statistical analysis was conducted utilizing SPSS software, version 23 (SPSS Inc., Chicago, IL, USA). One-way ANOVA (analysis of variance) and subsequent post-hoc tests were employed to ascertain statistical significance for both intra-group and inter-group variations. A significance level of $p<0.05$ was deemed meaningful, signifying a substantial distinction between the groups or circumstances under comparison.

Results

The dentin thickness that remains after retreatment using various file systems is displayed in Figures 2 to 4 of each group's nano-CT scans, while Figure 5 shows the mean percentage of dentin thickness that remains after endodontic retreatment.

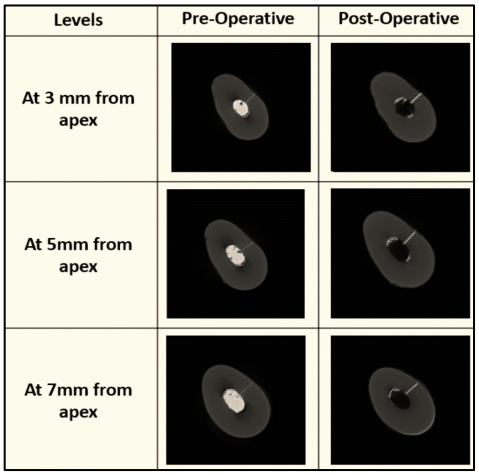

Figure 2. Three-dimensional reconstructed axial view of pre-operative and post operative at 3 mm, 5 mm, and 7 mm from the apex for Solite RS3.

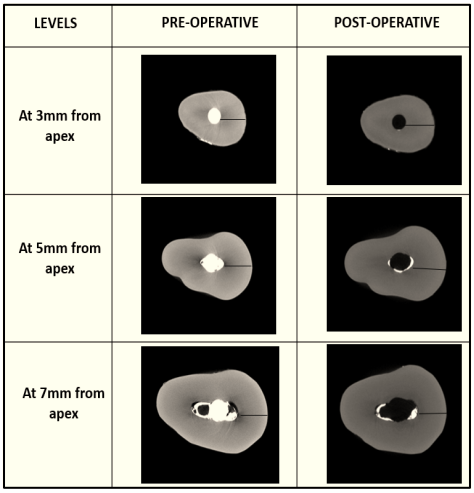

Figure 3. Three-dimensional reconstructed axial view of pre-operative and post-operative at 3 mm, 5 mm and 7 mm from the apex for Solite RS3 Black.

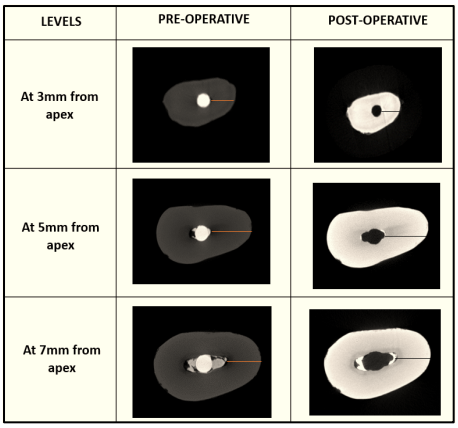

Figure 4. Three-dimensional reconstructed axial view of pre-operative and post-operative at 3 mm, 5 mm, and 7 mm from the apex for Solite RE Black.

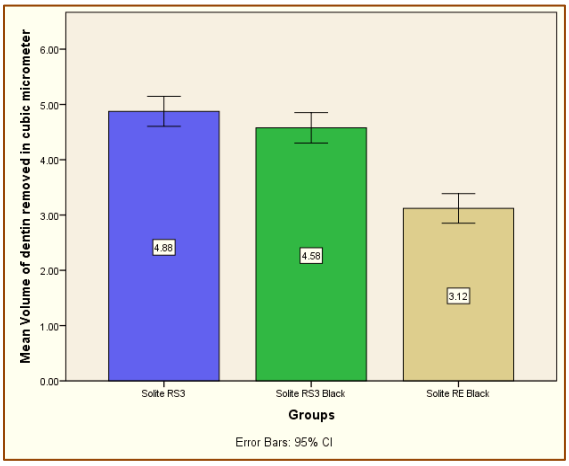

Figure 5. Represents various file systems for the mean volume of dentin removed after retreatment. Retreatment systems are shown on the X-axis, and the mean percentage of remaining dentin thickness is shown on the Y-axis. Solite RE black showed a lesser volume of dentin removed from the canal ($p<0.05$) compared to other file systems. Solite RS3 and Solite RS3 black showed no significant differences ($p>0.05$).

The proportion of removed dentin varied between the groups after retreatment, with a statistically significant variation ($p<0.05$). This leads to the rejection of the study's null hypothesis. Solite RE black removed a lesser volume of dentin when compared to other groups ($p<0.001$) (Table 1). One-way ANOVA showed a statistically significant difference in all the groups. Post hoc Tukey showed Solite RE black showed a significant difference when compared to Solite RS3 ($p<0.001$) and Solite RS3 black ($p<0.001$); no significant differences were seen between Solite RS3 and Solite RS3 Black ($p<0.204$).

Table 1. The distribution of the mean volume of dentin removed after retreatment.

Groups	Mean ± SD	p-value
Solite RS3	4.8750 ± 0.37992	<0.001
Solite RS3 Black	4.5770 ± 0.38552	
Solite RE Black	3.1200 ± 0.37357*	

*Indicates statistically significant difference when compared to other groups.

One-way ANOVA showed no statistically significant differences were found between all three groups ($p>0.05$) (Table 2).

Table 2. The distribution of dentinal crack defects between the three groups.

Groups	Mean ± SD	p-value
Solite RS3	1.6000 ± 0.51640	0.886
Solite RS3 Black	1.5000 ± 0.52705	
Solite RE Black	1.5000 ± 0.52705	

Discussion

Periapical inflammation or pain may also be caused by bacteria or residual necrotic tissue under the gutta-percha or sealer. In teeth undergoing endodontic treatment, resistant apical periodontitis is caused by bacterial colonies that continue to thrive within the complex root canal system [15]. Endodontic and post-endodontic treatment success may be predicted by the amount of dentin still present [1]. Hence, it is crucial to be more cautious during re-treatment procedures to prevent dentin loss. Excessive and forceful root canal re-instrumentation may lead to significant damage to the tooth's structural integrity, increasing the risk of fracture [16,17].

The main reason for selecting mandibular premolars is due to the prevalence of oval-shaped, as these canals pose challenges for instrumentation, and they often contain buccal and lingual extensions where microorganisms can persist, potentially contributing to root canal failure [18]. The mesial direction of excessive dentin removal occurs when circular cross-section rotary files are used [19]. The instruments used during retreatment directly impact the remaining thickness of the root dentin, which might have been affected during the root canal preparation, so care must be taken during this process. Therefore, selecting the appropriate files becomes crucial to effectively remove the obturating material while maintaining the dentin's thickness. Because instrumentation during retreatment directly affects the remaining root dentin thickness [20]. One possible element contributing to dentinal cracks is the taper of the files and the preparation. Using rotary NiTi files requires a lot more rotations in the canal than using hand files to complete the preparation. The development of dentinal defects may be facilitated by this technique [21].

The suggested techniques for determining the thickness of residual dentin and residual filling material are Micro Computed Tomography and Scanning Electron Microscopy [22]. For analysis, we employed nano

CT. This study suggested that Solite RE Black had a lower percentage of root dentin removal than Solite RS3 and Solite RS3 Black.

While the Solite RS3 system has an abundance of literature, the Solite RS3 Black and Solite RE Black are relatively new and hence lack literature, which is why the present study aims to compare these systems to the former. Assessing the previously done research on Solite RS3, we found that Sairaman et al. reported that the Solite RS3 retreatment file system achieved less dentin removal and stayed more centered in the canal, in comparison to ProTaper Universal retreatment files, owing to its enhanced flexibility from heat treatment, which also helps prevent excessive dentin removal due to its flexibility [20,23]. Shankar et al. noted that the Solite RS3 files removed less dentin than the HyFlex Remover files, as they had a lesser taper in comparison to the latter, thus minimizing dentin removal [18]. Similarly, Sowmya et al. found that the Solite RS3 files, compared to ProTaper retreatment files, preserved more root dentin due to their flexibility and alternating cutting edges and lesser taper, which effectively balance material removal with dentin conservation [17,19]. However, the results of our study state that the volume of dentin removed has a statistically significant difference between the Solite RE Black and the other files, with the former preserving more dentin.

This research is the first to compare the three retreatment file systems under nano CT in order to determine the proportion of cracked and volume of removed dentin. Because Solite RS3 files are heat-treated, they have less dentin removal and are a three-file system. Solite RS3 Black, composed of C wire technology, has less dentin removal and is a three-file system. Ultimately, Solite RE Black, a two-file system featuring a variable taper design and incorporating C wire technology, offers enhanced precision in dentin removal. and has less dentin removed because of its flexibility and variable taper design. As a result, these files are designed to effectively minimize dentin loss and prevent canal wall penetration. Only the analysis of teeth with a single root was included in the study. Clinical research into multirooted teeth and comparative analysis with alternative retreatment file systems may prove beneficial. It is important to recognize that, compared to micro-CT, nano-CT imaging demands significantly greater computer processing power. Additionally, the study's use of nanofocus mode was limited by the physical size of the roots, which can be considered a limitation of the present study. Future research should incorporate multiple retreatment file systems and curved canals to validate and expand upon these findings.

Conclusion

There were no notable variations in residual dentin thickness between Solite RS3 and Solite RS3 Black. However, Solite RE Black consistently demonstrated less dentin removal across all three levels. Nano-Ct analysis indicates that Solite RE Black caused less dentin loss compared to other groups. There were no significant differences in crack development among the retreatment files. Along with gutta-percha removal, careful consideration of dentin volume is crucial, as excessive tooth structure loss can jeopardize long-term success and increase the risk of crack formation and vertical root fractures.

Authors' Contributions

SS	https://orcid.org/0000-0002-7586-479X	Conceptualization, Methodology, Writing - Original Draft and Writing - Review and Editing.
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DPA	https://orcid.org/0000-0001-9509-3665	Investigation, Data Curation, Visualization and Project Administration.
KVT	https://orcid.org/0000-0003-0123-8873	Methodology, Formal Analysis, Writing - Review and Editing and Supervision.
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GM	https://orcid.org/0000-0002-8309-1272	Conceptualization and Writing - Review and Editing.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

References

[1] Jaggi P, Mulay S, Tandale A, Jadhao R, Joshi P, Aras S, et al. Comparative evaluation of debris extrusion, remaining dentin thickness and fracture resistance of endodontically treated teeth using rotary and reciprocating endodontic file systems: An in vitro study. Cureus 2023; 15(7):e42290. https://doi.org/10.7759/cureus.42290

[2] Rödig T, Hausdörfer T, Konietschke F, Dullin C, Hahn W, Hülsmann M. Efficacy of D-RaCe and ProTaper Universal retreatment NiTi instruments and hand files in removing gutta-percha from curved root canals - a micro-computed tomography study. Int Endod J 2012; 45(6):580-589. https://doi.org/10.1111/j.1365-2591.2012.02014.x

[3] Ali A, Saraf P, Kamatagi L, Khasnis S. Comparative assessment of canal transportation, dentin loss, and remaining root filling material by different retreatment files: An in vitro cross-sectional study. Contemp Clin Dent 2021; 12(1):14-20. https://doi.org/10.4103/ccd.ccd_31_20

[4] Kırıcı D, Demirbuga S, Karataş E. Micro-computed tomographic assessment of the residual filling volume, apical transportation, and crack formation after retreatment with Reciproc and Reciproc Blue Systems in curved root canals. J Endod 2020; 46(2):238-243. https://doi.org/10.1016/j.joen.2019.11.003

[5] Özyürek T, Tek V, Yılmaz K, Uslu G. Incidence of apical crack formation and propagation during removal of root canal filling materials with different engine driven nickel-titanium instruments. Restor Dent Endod 2017; 42(4):332-341. https://doi.org/10.5395/rde.2017.42.4.332

[6] 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):90-95. https://doi.org/10.15171/joddd.2017.017

[7] Das M, Shivakumar S, Das A, Mailankote S, Naik S, Sathydevi P. Assessment of root dentin defect during retreatment procedure using various NiTi hand and rotary retreatment files: An in vitro study. J Pharm Bioallied Sci 2022; 14(Suppl1):S573-S576. https://doi.org/10.4103/jpbs.jpbs_743_21

[8] Jain A, Nikhil V, Bansal P. Effect of root canal preparation, obturation, and retreatment on the induction of dentinal microcracks: A microcomputed tomography study. J Conserv Dent 2018; 21(5):521-525. https://doi.org/10.4103/JCD.JCD_184_18

[9] Swathi S, Antony DP, Solete P, Jeevanandan G, Vishwanathaiah S, Maganur PC. Comparative evaluation of remaining dentin thickness, canal centering ability and apical deformity between ProFit S3 and Protaper gold – A nano CT study. Saudi Dent J 2024; 36(4):650-655. https://doi.org/10.1016/j.sdentj.2024.01.002

[10] Sowmya MR, Solete P, Jeevanandan G, Sugumaran Surendar, Shetty Bavabeedu S, Shaiban A, et al. Influence of heat treated files on conserving the remaining dentin thickness during endodontic retreatment – An invitro CBCT study. J King Saud University - Science 2023; 35:102969. https://doi.org/10.1016/j.jksus.2023.102969

[11] Antony SDP, Subramanian AK, Nivedhitha MS, Solete P. Comparative evaluation of canal transportation, centering ability, and dentin removal between ProTaper Gold, One Curve, and Profit S3: An in vitro study. J Conserv Dent 2020; 23(6):632-636. https://doi.org/10.4103/JCD.JCD_619_20

[12] Abdelnaby P, Ibrahim M, ElBackly R. In vitro evaluation of filling material removal and apical debris extrusion after retreatment using Reciproc blue, Hyflex EDM and ProTaper retreatment files. BMC Oral Health 2023; 23(1):902. https://doi.org/10.1186/s12903-023-03579-7

[13] Valan AS, Solete P, Jeevanandan G, Antony DPS, Kavoor S. Influence of heat-treated retreatment files on the canal transportation and centering ability during retreatment: An in vitro cone beam computed tomography study. J Int Oral Health 2023; 15(3):278-283. https://doi.org/10.4103/jioh.jioh_270_22

[14] Nagendrababu V, Murray PE, Ordinola-Zapata R, Peters OA, Rôças IN, Siqueira JF Jr, et al. PRILE 2021 guidelines for reporting laboratory studies in Endodontology: Explanation and elaboration. Int Endod J 2021; 54(4):1491-1515. https://doi.org/10.1111/iej.13542

[15] Kulkarni NR, Kamat SB, Hugar SI, Nanjannawar GS, Patil PD. Evaluation of remaining dentin thickness following use of three different rotary nickel-titanium retreatment files: A cone-beam computed tomography study. J Conserv Dent 2019; 22(6):588-592. https://doi.org/10.4103/JCD.JCD_269_19

[16] Ganesh A, Venkateshbabu N, John A, Deenadhayalan G, Kandaswamy D. A comparative assessment of fracture resistance of endodontically treated and re-treated teeth: An in vitro study. J Conserv Dent 2014; 17(1):61-64. https://doi.org/10.4103/0972-0707.124146

[17] Krishnan V, Nair RS, Ashok L, Angelo MC. An overview of thermomechanically heat-treated nickel–Titanium alloy used in endodontics. Conserv Dent Endod J 2019; 4:34-38. https://doi.org/10.5005/jp-journals-10048-0047

[18] Teja KV, Janani K, Srivastava KC, Shrivastava D, Natoli V, Di Blasio M, et al. Comparative evaluation of antimicrobial efficacy of different combinations of calcium hydroxide against Enterococcus faecalis. BMC Oral Health 2023; 23(1):849. https://doi.org/10.1186/s12903-023-03552-4

[19] Choudhari S, Solete P, Jeevanandan G, Teja KV, Antony DP, Ramesh S. Single-visit versus multi-visit endodontic retreatment: A systematic review of outcomes in patients with secondary endodontic infection. Saudi Endod J 2024; 14(3):301-311. https://doi.org/10.4103/sej.sej_225_23

[20] Sankar A, Solete P, Jeevanandan G, Priscilla Antony D, Arun N, Raghu S. Comparative evaluation of Solite RS3 and HyFlex remover retreatment files in conserving remaining dentin thickness during endodontic retreatment using cone beam computed tomography: An in vitro analysis. Cureus 2024; 16(4):e57805. https://doi.org/10.7759/cureus.57805

[21] Bier CAS, Shemesh H, Tanomaru-Filho M, Wesselink PR, Wu M-K. The ability of different nickel-titanium rotary instruments to induce dentinal damage during canal preparation. J Endod 2009; 35(2):236-238. https://doi.org/10.1016/j.joen.2008.10.021

[22] Reddy GS, Kalaiselvam R, Rajakumaran A, Kuzhanchinathan M, Sabarish R, Ganesh A. Evaluation of root dentin thickness and smear layer removal efficacy of two novel nickel titanium rotary instruments - An in vitro cone-beam computed tomography and scanning electron microscopy study. J Pharm Bioallied Sci 2021; 13(Suppl 2): S1628–S1632. https://doi.org/10.4103/jpbs.jpbs_346_21

[23] Sairaman S, Solete P, Jeevanandan G, Antony SDP, Kavoor S, Adimulapu HS. Comparative analysis of novel heat-treated retreatment file system on the removal of obturating material using nano-computed tomography. J Conserv Dent Endod 2024; 27(1):82-86. https://doi.org/10.4103/JCDE.JCDE_224_23