Brazilian Dental Science

unesp
UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE

DOI: https://doi.org/10.4322/bds.2024.e4369

Comparative evaluation of the canal transportation after retreatment with Solite RS3 and Protaper Universal retreatment files: a nano computed tomography study

Avaliação comparativa do desvio do canal após retratamento endodôntico com limas de retratamento Solite RS3 e Protaper Universal: um estudo de nano tomografia computadorizada

Sruthi SAIRAMAN[1], Pradeep SOLETE[1], Ganesh JEEVANANDAN[2], Divya SENA[1], Kavalipurapu Venkata TEJA[3], Mohammed MUSTAFA[4]

1 - Saveetha University, Saveetha Institute of Medical and Technical Sciences, Saveetha Dental College and Hospitals, Department of Conservative Dentistry and Endodontics. Chennai, India.
2 - Saveetha University, Saveetha Institute of Medical and Technical Sciences, Department of Pediatric and Preventive Dentistry Saveetha Dental College and Hospitals. Chennai, India.
3 - Mamata Institute of Dental Sciences, Department of Conservative Dentistry and Endodontics. Hyderabad, Telangana, India.
4 - Prince Sattam Bin Abdulaziz University, College of Dentistry, Department of Conservative Dental Sciences. Al-Kharj, Saudi Arabia.

How to cite: Sairaman S, Solete P, Jeevanandan G, Sena D, Teja KV, Mustafa M. Comparative evaluation of the canal transportation after retreatment with Solite RS3 and Protaper Universal retreatment files: a nano computed tomography study. Braz Dent Sci. 2024;27(3):e4369. https://doi.org/10.4322/bds.2024.e4369

ABSTRACT

Objective: The primary objective of instrumentation during retreatment is to preserve the original curvature of the canal while removing gutta-percha. The current study assesses the canal transportation after retreatment with two different retreatment file systems. **Materials and Methods:** Sixty single-rooted teeth, extracted and decoronated, were obturated at a standardized root length of 16 mm. The samples were then divided into two groups, each comprising 20 single-rooted teeth. The instrumentation was performed using Solite RS3 Retreatment files for one group and ProTaper Retreatment files for the other. After both pre-operative and post-operative nano-CT scans, 3D reconstruction was conducted for analysis. Sections of the pre-operative and post-operative samples were taken at 7 mm, 5 mm, and 3 mm and 1 mm from the apex to calculate the canal transportation. Statistical analysis between the two groups was carried out using an independent t-test. **Results:** Solite RS3 retreatment files exhibited a statistically significant difference at all three levels ($p < 0.05$) when compared to ProTaper retreatment files, thus showing lesser canal transportation than the latter. **Conclusion:** Based on the above results, it can be concluded that Solite RS3 induced minimal canal transportation and resulted in a relatively centered preparation compared to the ProTaper Retreatment system.

KEYWORDS

Canal transportation; Nano-CT; Remaining dentin thickness; Retreatment; Solite RS3.

RESUMO

Objetivo: O objetivo principal da instrumentação durante o retratamento é preservar a curvatura original do canal durante a remoção da guta-percha. O presente estudo avalia o desvio do canal após o retratamento endodôntico com dois sistemas de limas de retratamento diferentes. **Material e Métodos:** Sessenta dentes uniradiculares, extraídos e com as coroas removidas, foram obturados em um comprimento de raiz padronizado de 16 mm. As amostras foram então divididas em dois grupos, cada um com 20 dentes uniradiculares. O preparo biomecânico foi realizado utilizando limas de retratamento Solite RS3 para um grupo e limas de retratamento ProTaper para o outro. Após o escaneamento pré e pós-operatórias no nano-CT, a reconstrução 3D foi conduzida para análise. Secção das amostras pré e pós-operatórias foram retiradas a 7 mm, 5 mm e 3 mm e 1mm do ápice para

calcular o desvio do canal. A análise estatística entre os dois grupos foi realizada através do teste t independente. **Resultados**: As limas de retratamento Solite RS3 exibiram uma diferença estatisticamente significativa em todos os três níveis ($p < 0,05$) quando comparadas às limas de retratamento ProTaper, mostrando, portanto, menor desvio de canal do que estas últimas. **Conclusão:** Com base nos resultados acima, pode-se concluir que as limas Solite RS3 induziu o desvio de canal mínimo e resultou em uma preparação relativamente centralizada em comparação ao sistema de retratamento ProTaper.

PALAVRAS-CHAVE

Desvio de canal; Nano-CT; Espessura de dentina remanescente; Retratamento; Solite RS3.

INTRODUCTION

The prognosis of a root canal treatment is dependent on the complete elimination or, at the very least, a substantial reduction in bacterial load [1]. However, multiple studies have confirmed the development of apical periodontitis in 30 to 44.9% of root canal-treated teeth [2,3]. In such cases, the preferred and recommended line of treatment is non-surgical endodontic retreatment [4] Over the years, many methods including manual instrumentation, rotary systems, ultrasonics, and reciprocation systems have been used to eliminate the previously existing filling material [5]. Ongoing research and advancements in both instrument design and techniques have resulted in the development of numerous retreatment file systems. Several variables, such as surface treatment, active cutting tip, cross-sectional design, cutting angle, and taper significantly influence the effectiveness of these systems and the duration of gutta-percha removal (GP) [6]. In cases of non-surgical endodontic retreatment, after retrieving the previous filling material, the canal must be enlarged and debrided sufficiently to allow adequate disinfection while maintaining the canal curvature. [7] Nickel-titanium (NiTi) instruments have proven to be more effective in shaping the root canals in comparison to manual instrumentation [8]. Their use ensures the preservation of the canal anatomy and the precise positioning of the apical foramen, resulting in well-tapered root canal preparations. During cleaning and shaping procedural errors such as ledge formation, canal blockage, apical transportation, and root perforations tend to occur which decreases the success rate of endodontic retreatment [9,10]. Excessive dentin removal results in the tooth being more susceptible to root fractures, especially if additional forces are used during the obturation or restoration stage [11]. When canal preparation is off-centric, the excessive removal of dentin from one side causes a change in stress distribution in the buccolingual plane and increased root flexure [12]. A vertical root fracture of the tooth is made more likely by this change in the distribution of radicular stress from the cervical to the apical dentin [12]. Transportation, as defined by the American Association of Endodontists in The Glossary of Endodontic Terms (2015), refers to the removal of the canal wall structure on the outer curve in the lower half of the canal. This occurs because files have a tendency to return to their original straight shape during the preparation of the canal. Apical transportation will result in difficulty in obtaining a stop for apical gutta-percha, incorrect apical seal, and even extrusion of irrigants and sealers which may adversely affect the periodontium [13]. Root canal treatment failure includes inadequate obturation, inadequate cleaning, shape, disinfection, instrument separation, presence of a persistent periapical lesion, and violation of the apical foramen [14,15]. In recent years, numerous retreatment systems have become available, and this study specifically evaluates two retreatment file systems: Solite RS3 Retreatment file system (Solite Dental, India) and ProTaper Universal Retreatment (Dentsply Maillefer, Ballaigues, Switzerland). Each of these systems comprises three files, with each file specifically designated for the removal of gutta-percha from the coronal, middle, and apical thirds of the root canal. The ProTaper Retreatment files (Dentsply Maillefer, Ballaigues, Switzerland) have been thoroughly studied in the past for their effectiveness and safety in both straight and curved canals [16-21]. The current study evaluates the effect of different metallurgy-based retreatment file systems on canal transportation during gutta percha retrieval utilizing nano-computed tomography. Nano-CT represents a technological advancement over conventional micro-computed tomography, with a significantly reduced focal spot size of 400 nm compared to the

latter's range of 5–50 μm [22]. This advancement ensures a more precise scan for assessing dentin thickness and therefore canal transportation. The study aims to superimpose the nano-CT scans obtained before and after the removal of filling material, analyzing the canal transportation remaining at 1 mm, 3 mm, 5 mm, and 7 mm from the apex. The null hypothesis posits that there is no disparity in canal transportation at different levels between the two retreatment systems.

MATERIALS AND METHODS

This study was done following the PRILE guidelines as described in Flowchart 1 [23] The sample size for the present study was calculated from a previous study which assessed canal transportation between two retreatment file systems using Cone Beam Computerised Tomography [24]. Based on the assessment a total sample size of 60 was calculated at a power of 95% ($1 - \beta = 0.95$, $\alpha = 0.05$).

Sixty single-rooted teeth with straight canals (curvature of less than 5 degrees) [25] were chosen for this study. Teeth with pulp stones, resorptive defects, previous root canal therapy, cracks, and fractures were excluded from the study. Radiographic assessments were conducted on each tooth to identify any deformities, and those with deformities were excluded. To establish a consistent working length of 16 mm [26], the teeth were subjected to decoronation using diamond discs. The access was subsequently established using an Endo Access Bur 2 (Dentsply Maillefer, Ballaigues, Switzerland). A 2.5 mL solution of 3% sodium hypochlorite (Prime Dental, India) was used to clean the canal. To verify that the canal is clear, 10K files (Mani, Japan) were used until the end of the file could be seen at the tip of the tooth apex, and the working length was estimated to be 0.5 mm less than this measurement. For the chemomechanical preparation, ProFit S3 (ProFit Dental, India) [27,28] was employed up to PF3, with irrigation using 2.5 mL of 3% sodium hypochlorite between each file. After drying the canals with paper points, root canal filling was performed using PF3 gutta-percha(GP) cones (ProFit Dental, India) and AH Plus sealer (Dentsply DeTrayGmBH, Konstanz, Germany) employing the single cone matched taper technique. Excess gutta-percha at the canal orifice level was removed using a heated plugger. The adequacy of the filling was assessed through periapical radiographs, ensuring homogeneity and the absence of voids. Insufficient root canal fillings were replaced after removal. Orifices were sealed with a composite restoration (Neospectra ST, Dentsply Sirona, USA). The specimens were stored for two weeks in a 1.5-mL graduated Eppendorf microcentrifuge tube that was filled with distilled water. The storage temperature was consistently maintained at 37°C, while the humidity level was consistently maintained at 100%. This storage condition was necessary to guarantee that the sealer completely solidified. A solitary operator conducted all endodontic treatments.

Nano- CT scanning

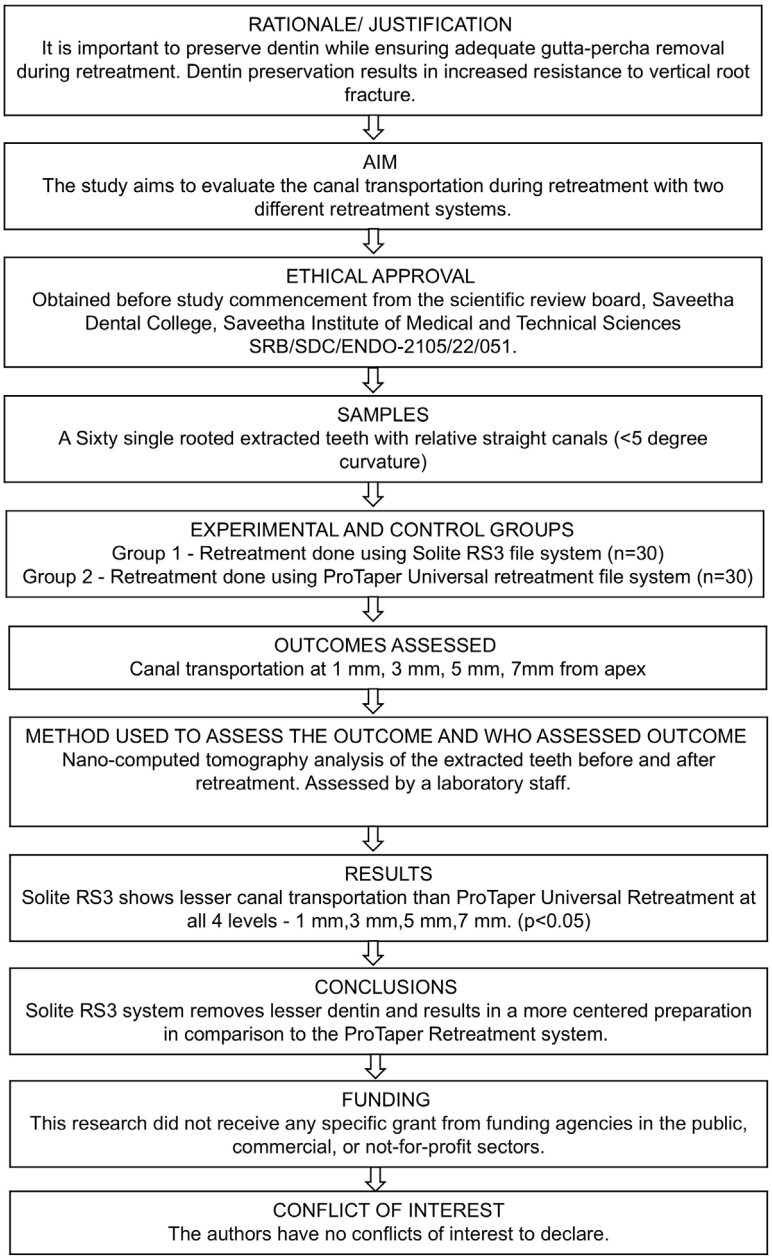
The Bruker SKYSCAN2214 scanner from Bruker Micro-CT in Kontich, Belgium, known for its high precision, was employed for scanning the prepared specimens. Scan parameters comprised 100 kV (10W and 100A), 1100 ms exposure, and a flat panel detector with 360° rotation and 0.3° rotation step. The NRecon software from Bruker-microCT in Kontich, Belgium, utilizing a modified Feldkamp cone-beam reconstruction algorithm, was utilized for image reconstruction. The original grayscale images underwent fine-tuning functions, such as a Gaussian filter (smoothing, kernel = 2), 40% beam hardening correction, 0.50 post-alignment, and ring artifact correction of 10 to address potential acquisition misalignment. The image was then scaled to a fixed row and column size of 1944 x 3072, with a pixel size of 11999.58 nm.

Retreatment procedure

Sixty samples (N=60) were randomly allocated into each of the two categories of specimens. Group 1 underwent retreatment using the Solite RS3 (n=30) retreatment file system (Solite Dental, India), while Group 2 received retreatment with the ProTaper Universal retreatment file systems (n=30) (Dentsply Maillefer, Ballaigues, Switzerland). Both systems included files for the coronal, middle, and apical thirds of the root canal system GP retrieval.

Specifications of the retreatment files

- Solite RS3: RS1 (30/.08, 15 mm), RS2 (25/.07, 18 mm), RS3 (20/.06, 23 mm)
- ProTaper Retreatment File System: D1 (30/.09, 16 mm), D2 (25/.08, 18 mm), D3 (20/.07, 22 mm)



Flowchart 1 - Methodology flowchart according to PRILE guidelines.

Manufacturer instructions were followed, and no solvent was used during the procedure. Irrigation was performed using 3% sodium hypochlorite- 2.5mL. After the final file use, the canals were irrigated again with 3% sodium hypochlorite 10 mL, followed by regular saline 10 mL, and dried with paper points. Files were discarded after four uses or when noticeable changes were observed in the flutes.

Retreatment was considered complete when files reached the working length, dentinal walls were smooth, and no filling material was visible under an optical microscope. A second scan of each sample was conducted using the SKYSCAN2214 scanner with the same settings.

Nano-CT imaging analysis and measurements

Sections of the tooth at 1 mm, 3 mm, 5 mm, and 7 mm levels from the apex were made to both preoperative and postoperative scans as described by Gambill et al. [29] To assess the apical transportation, the distance from the margin of the filled samples to the external root border was calculated. The same measurements were then repeated after GP retrieval.

Canal transportation is measured as (m1 - m2) - (d1 - d2), where m1, d1 are the shortest distances from the mesial and distal edges of the root, respectively, to the related edges of the filled canal, and m2, d2 are the shortest

distances from the mesial and distal edges of the root, respectively, to the related edges of the canal after GP retrieval by Gambill et al. [29] Pre and post-measurements of canal transportation for Solite RS3 is represented in Figure 1 and for ProTaper Retreatment is represented in Figure 2 using Nano CT respectively.

Statistical analysis

SPSS software (IBM Corp, SPSS Inc, Chicago, IL, USA) version 23 was used for statistical data analysis. Normality was assessed using the Shapiro-Wilk test, and as the results were found to be parametric, the independent t-test was applied at a 95% confidence interval.

RESULTS

The mean canal transportation and standard deviation values (μm) at the 3 levels for both the file systems respectively are represented in Table I. The results show that Solite RS3 showed lesser deviation from original canal morphology than ProTaper retreatment at the 4 levels - 1 mm, 3 mm, 5 mm, and 7 mm from the apex ($p<0.05$).

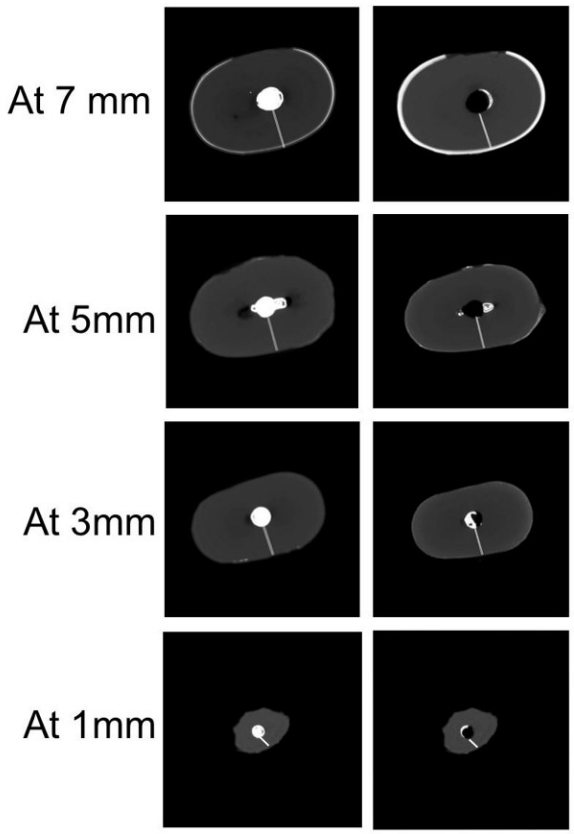


Figure 1 - Represents the measurement of the shortest distance between the canal and edge of the root pre and pos retreatment using Solite RS3 system.

DISCUSSION

Ensuring a smooth and tapered preparation from the canal orifice to the apex while simultaneously preserving the canal morphology presents a challenge in the context of endodontic retreatment, as the canal has already undergone instrumentation by the previous operator [30]. Endodontic literature has consistently re-established that canal instrumentation often results in the straightening of the canal, leading to a modification of the initial canal anatomy [31]. Typically, this straightening manifests on the outer canal wall, resulting in a preparation that exhibits slight deviation towards one side [32]. The current study evaluates canal transportation in standardized samples with relatively straight canals during retreatment to discern the degree to which the retreatment system influences such deviations, considering that the shaping of canals is considerably less operator-dependent due to the canals being relatively straight. The canal transportation is calculated at different specified levels: 1 mm, 3 mm, 5 mm, and 7mm from the apex, adhering to the standard methodology adopted in computed tomography analysis [29].

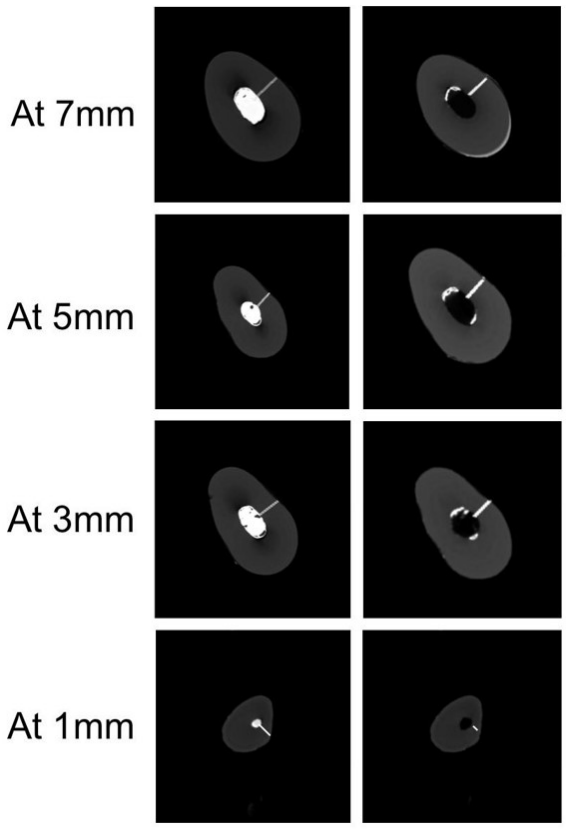


Figure 2 - Represents the measurement of the shortest distance between the canal and edge of the root pre and pos retreatment using ProTaper Universal retreatment system.

Nano-CT employs a high-power nanofocus X-ray source for accurately characterizing and quantifying tissue microarchitectures [33]. While micro-CT has long been regarded as the gold standard for analyzing shaping ability and obturation quality, recent studies highlight the nuanced capabilities of nano-CT, capable of detecting changes that micro-CT may not precisely determine, which is why the present study has chosen this modality for analysis [34].

The introduction of NiTi alloys revolutionized endodontic treatment, significantly enhancing the quality of root canal procedures [35]. Despite their numerous advantages, such as super elasticity and preservation of original canal morphology, NiTi alloys exhibit an undesirable shape memory effect [36,37]. This effect, likely responsible for root canal transportation, can lead to a loss in centering ratio and alteration of the original canal anatomy. Consequently, certain areas of the canal may remain untouched, resulting in dentin loss and inefficient cleaning [38]. To address these challenges, thermal treatment of NiTi alloys was introduced to enhance flexibility, increase cyclic and torsional fatigue resistance, and eliminate the undesirable shape memory effect [39,40] [41]. This thermal treatment renders the instruments more deformable with pseudo-elasticity, introducing a controlled memory effect [41]. Instruments subjected to thermomechanical treatment reduce root canal transportation by avoiding the straightening of curved root canals during preparation [42].

The observed statistical disparity in apical transportation between the Solite RS3 and ProTaper Universal retreatment systems can be attributed to its thermomechanical treatment. The Solite RS3 file, being heat-treated, exhibits better flexibility, and its taper is less than that of ProTaper, leading to dentine preservation and preventing canal transportation. The D3 file in the ProTaper Universal retreatment system has a 7% taper at the tip, causing the file to be stiff and leading to an off-centered preparation in comparison to Solite RS3 while aside from its thermomechanical treatment, has a taper of 6% at the tip [43]. This discrepancy results in the observed difference in dentin loss and transportation at the apical level. The lower canal centering ability also implies reduced remaining dentin thickness on one side of the root, as established by the literature, which indicates that retreatment induces more dentinal defects compared to primary endodontic treatment [44].

In addition to achieving clinical success outcomes by reducing bacterial load and attaining a sound coronal and apical seal, clinicians should consider the long-term durability of the treated tooth to prevent catastrophic failures, such as vertical root fractures. Endodontically treated teeth are predisposed to a higher susceptibility to fractures, primarily attributed to alterations in canal curvature, cross-section, and the loss of circumferential dentin, thereby influencing stress distribution across the root dentin [45-47]. The choice of retreatment system plays a crucial role in determining the extent of dentinal loss, and higher taper systems, like ProTaper, may contribute to increased root flexure and susceptibility to vertical root fractures [48]. Even the choice of glide path and operator experience clinically alters the pain [49,50].

The ProTaper Retreatment system remains widely tested and used as it was the first retreatment file system to be introduced, prompting the present study to compare its efficacy with the

Table I - Represents the Mean and standard deviation values (μm) of the canal transportation for both the groups at 1 mm, 3 mm,5 mm, and 7 mm respectively. At all levels, Solite RS3 showed a statistically significant difference compared to ProTaper retreatment files (p<0.05)

Groups		Mean ± Std. Deviation (μm)	p value
At 7 mm from apex	Solite RS3	0.0220 ± 0.0154	p = 0.011*
	ProTaper Retreatment	0.0410 ± 0.0347	
At 5 mm from Apex	Solite RS3	0.0280 ± 0.0139	p = 0.029*
	ProTaper Retreatment	0.0340 ± 0.0217	
At 3 mm from Apex	Solite RS3	0.0270 ± 0.0116	p = 0.012*
	ProTaper Retreatment	0.0320 ± 0.0204	
At 1 mm from Apex	Solite RS3	0.0260 ± 0.0084	p = 0 .002*
	ProTaper Retreatment	0.0300 ± 0.0182	

*Indicates statistically significant difference (p<0.05).

relatively new Solite RS3 system. Although the current study assesses apical transportation in relatively straight canals, other parameters such as remaining filling material, remaining dentin thickness after retreatment, and crack propagation need evaluation to determine the optimal file system for retreatment, posing a limitation to the study.

It is essential to acknowledge that, compared to micro-CT, nano-CT imaging significantly taxes computer processing. The study's inability to use the nanofocus mode due to physical limitations in root size adds to this consideration. Further research incorporating multiple retreatment file systems and curved canals is recommended to validate and extend these findings. Based on the findings presented, it is reasonable to conclude that Solite RS3 induces minimal canal transportation and yields a more centrally positioned preparation compared to the ProTaper Retreatment system. The observed attributes of Solite RS3, including its heat treatment and lower taper, position it as a promising retreatment file system. These features contribute to effective gutta-percha removal while concurrently preserving dentin integrity.

CONCLUSION

Based on the findings presented, it is reasonable to conclude that Solite RS3 induces minimal canal transportation and yields a more centrally positioned preparation compared to the ProTaper Retreatment system. The observed attributes of Solite RS3, including its heat treatment and lower taper, position it as a promising retreatment file system. These features contribute to effective gutta-percha removal while concurrently preserving dentin integrity.

Acknowledgements

The authors would like to acknowledge The White Lab, Saveetha Dental College for their help in carrying out the nano-computed tomography study.

Author's Contributions

SS, PS, GJ, DS, KVT, MM: Methodology, Writing – Review & Editing. SS, DS, KVT, MM: Data Curation Writing – Original Draft Preparation. SBD: Funding Acquisition. PS, GJ: Conceptualization, Software, Validation, Formal Analysis, Visualization, Supervision, Project Administration.

Conflict of Interest

The authors have no conflicts of interest to declare.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Regulatory Statement

This study protocol was reviewed and approved by the SRB committee at Saveetha Dental College, Saveetha Institute of Medical and Technical Sciences,Chennai, India approval number SRB/SDC/ENDO-2105/22/051.

REFERENCES

1. Tandon J, Taneja S, Bhalla VK, Jain A. Evaluation of bacterial reduction at various stages of endodontic retreatment after use of different disinfection regimens: an in vivo study. Eur Endod J. 2022;7(3):210-6. http://doi.org/10.14744/eej.2022.42713 PMid:36217643.
2. Kielbassa AM, Frank W, Madaus T. Radiologic assessment of quality of root canal fillings and periapical status in an Austrian subpopulation: an observational study. PLoS One. 2017;12(5):e0176724. http://doi.org/10.1371/journal.pone.0176724 PMid:28464019.
3. Boucher Y, Matossian L, Rilliard F, Machtou P. Radiographic evaluation of the prevalence and technical quality of root canal treatment in a French subpopulation. Int Endod J. 2002;35(3):229-38. http://doi.org/10.1046/j.1365-2591.2002.00469.x PMid:11985674.
4. Torabinejad M, Corr R, Handysides R, Shabahang S. Outcomes of nonsurgical retreatment and endodontic surgery: a systematic review. J Endod. 2009;35(7):930-7. http://doi.org/10.1016/j.joen.2009.04.023 PMid:19567310.
5. Gomes NN, de Carvalho GM, Júnior ECS, Garcia LDFR, Marques AAF, de Carvalho FMA. Filling material removal with reciprocating and rotary systems associated with passive ultrasonic irrigation. Eur Endod J. 2017;2(1):1-7. http://doi.org/10.5152/eej.2017.16037 PMid:33403335.
6. 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):580-9. http://doi.org/10.1111/j.1365-2591.2012.02014.x PMid:22264204.
7. Conceição Limongi PBO, Amaral AP, Pelegrine RA, da Silveira Bueno CE, Kato AS, de Martin AS, et al. Removal of obturation material from root canals using a combination of reciprocal instrumentation and different final irrigation techniques. Iran Endod J. 2020;15(3):147-54. PMid:36703806.

8. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14(7):346-51. http://doi.org/10.1016/S0099-2399(88)80196-1 PMid:3251996.

9. Alrahabi M, Zafar MS, Adanir N. Aspects of clinical malpractice in endodontics. Eur J Dent. 2019;13(3):450-8. http://doi.org/10.1055/s-0039-1700767 PMid:31795008.

10. Mantri SP, Kapur R, Gupta NA, Kapur CA. Type III apical transportation of root canal. Contemp Clin Dent. 2012;3(1):134-6. http://doi.org/10.4103/0976-237X.94565 PMid:22557916.

11. Patel S, Bhuva B, Bose R. Present status and future directions: vertical root fractures in root filled teeth. Int Endod J. 2022;55(Suppl 3):804-26. http://doi.org/10.1111/iej.13737 PMid:35338655.

12. Ossareh A, Rosentritt M, Kishen A. Biomechanical studies on the effect of iatrogenic dentin removal on vertical root fractures. J Conserv Dent. 2018;21(3):290-6. http://doi.org/10.4103/JCD.JCD_126_18 PMid:29899632.

13. Wu MK, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. J Endod. 2000;26(4):210-6. http://doi.org/10.1097/00004770-200004000-00003 PMid:11199720.

14. Siqueira JF Jr. Aetiology of root canal treatment failure: why well-treated teeth can fail. Int Endod J. 2001;34(1):1-10. http://doi.org/10.1046/j.1365-2591.2001.00396.x PMid:11307374.

15. Tabassum S, Khan FR. Failure of endodontic treatment: the usual suspects. Eur J Dent. 2016;10(1):144-7. http://doi.org/10.4103/1305-7456.175682 PMid:27011754.

16. Giuliani V, Cocchetti R, Pagavino G. Efficacy of ProTaper universal retreatment files in removing filling materials during root canal retreatment. J Endod. 2008;34(11):1381-4. http://doi.org/10.1016/j.joen.2008.08.002 PMid:18928852.

17. Gu L-S, Ling J-Q, Wei X, Huang X-Y. Efficacy of ProTaper Universal rotary retreatment system for gutta-percha removal from root canals. Int Endod J. 2008;41(4):288-95. http://doi.org/10.1111/j.1365-2591.2007.01350.x PMid:18081804.

18. Fariniuk LF, Azevedo MAD, Carneiro E, Westphalen VPD, Piasecki L, da Silva Neto UX. Efficacy of protaper instruments during endodontic retreatment. Indian J Dent Res. 2017;28(4):400-5. http://doi.org/10.4103/ijdr.IJDR_89_16 PMid:28836531.

19. Ciftcioglu E, Sungur Guzel R, Akbal Dincer G, Karakaya G, Kucukay ES. Efficiency of ProTaper Universal Retreatment, Reciproc Blue and XP-endo Shaper in the removal of a bioceramic-based root canal filling. Eur Oral Res. 2023;57(3):159-64. PMid:37929225.

20. Ma J, Al-Ashaw AJ, Shen Y, Gao Y, Yang Y, Zhang C, et al. Efficacy of ProTaper Universal Rotary Retreatment system for gutta-percha removal from oval root canals: a micro-computed tomography study. J Endod. 2012;38(11):1516-20. http://doi.org/10.1016/j.joen.2012.08.001 PMid:23063227.

21. Ozyurek T, Ozsezer-Demiryurek E. Efficacy of protaper next and protaper universal retreatment systems in removing gutta-percha in curved root canals during root canal retreatment. J Istanb Univ Fac Dent. 2017;51(2):7-13. http://doi.org/10.17096/jiufd.97431 PMid:28955590.

22. Haugen HJ, Qasim SB, Matinlinna JP, Vallittu P, Nogueira LP. Nano-CT as tool for characterization of dental resin composites. Sci Rep. 2020;10(1):15520. http://doi.org/10.1038/s41598-020-72599-y PMid:32968120.

23. 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: A consensus-based development. Int Endod J. 2021;54(9):1482-90. http://doi.org/10.1111/iej.13542 PMid:33938010.

24. Solete P, Valan A, Jeevanandan G, Antony S DP, 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. http://doi.org/10.4103/jioh.jioh_270_22.

25. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol. 1971;32(2):271-5. http://doi.org/10.1016/0030-4220(71)90230-1 PMid:5284110.

26. 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):82-6. http://doi.org/10.4103/JCDE.JCDE_224_23 PMid:38389750.

27. 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):650-5. http://doi.org/10.1016/j.sdentj.2024.01.002 PMid:38690382.

28. 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 study. J Conserv Dent. 2020;23(6):632-6. http://doi.org/10.4103/JCD.JCD_619_20 PMid:34083922.

29. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996;22(7):369-75. http://doi.org/10.1016/S0099-2399(96)80221-4 PMid:8935064.

30. Gergi R, Rjeily JA, Sader J, Naaman A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. J Endod. 2010;36(5):904-7. http://doi.org/10.1016/j.joen.2009.12.038 PMid:20416443.

31. Hasheminia SM, Farhad A, Sheikhi M, Soltani P, Hendi SS, Ahmadi M. Cone-beam computed tomographic analysis of canal transportation and centering ability of single-file systems. J Endod. 2018;44(12):1788-91. http://doi.org/10.1016/j.joen.2018.09.011 PMid:30390970.

32. Yammine S, Jabbour E, Diemer F, Majzoub Z. Canal straightening following overinstrumentation with three nickel-titanium rotary instruments. J Int Soc Prev Community Dent. 2018;8(3):245-51. http://doi.org/10.4103/jispcd.JISPCD_18_18 PMid:29911063.

33. Peyrin F, Dong P, Pacureanu A, Langer M. Micro- and nano-CT for the study of bone ultrastructure. Curr Osteoporos Rep. 2014;12(4):465-74. http://doi.org/10.1007/s11914-014-0233-0 PMid:25292366.

34. Huang Y, Celikten B, de Faria Vasconcelos K, Ferreira Pinheiro Nicolielo L, Lippiatt N, Buyuksungur A, et al. Micro-CT and nano-CT analysis of filling quality of three different endodontic sealers. Dentomaxillofac Radiol. 2017;46(8):20170223. http://doi.org/10.1259/dmfr.20170223 PMid:28845679.

35. Versiani MA, Basrani B, Sousa-Neto MD. The root canal anatomy in permanent dentition. Cham: Springer; 2018.

36. Schäfer E, Bürklein S. Impact of nickel-titanium instrumentation of the root canal on clinical outcomes: a focused review. Odontology. 2012;100(2):130-6. http://doi.org/10.1007/s10266-012-0066-1 PMid:22527909.

37. Tabassum S, Zafar K, Umer F. Nickel-titanium rotary file systems: what's new? Eur Endod J. 2019;4(3):111-7. PMid:32161896.

38. Kandaswamy D, Venkateshbabu N, Porkodi I, Pradeep G. Canal-centering ability: an endodontic challenge. J Conserv Dent. 2009;12(1):3-9. http://doi.org/10.4103/0972-0707.53334 PMid:20379433.

39. Silva EJNL, Giraldes JFN, de Lima CO, Vieira VTL, Elias CN, Antunes HS. Influence of heat treatment on torsional resistance and surface roughness of nickel-titanium instruments. Int Endod J. 2019;52(11):1645-51. http://doi.org/10.1111/iej.13164 PMid:31132156.

40. Chan W-S, Gulati K, Peters OA. From heat treatment to surface functionalization for nickel-titanium (NiTi) instruments in endodontics. Bioact Mater. 2023;22:91-111. http://doi.org/10.1016/j.bioactmat.2022.09.008 PMid:36203965.

41. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - a review. Int Endod J. 2018;51(10):1088-103. http://doi.org/10.1111/iej.12924 PMid:29574784.

42. Silva EJNL, Martins JNR, Lima CO, Vieira VTL, Braz Fernandes FM, De-Deus G, et al. Mechanical tests, metallurgical characterization, and shaping ability of nickel-titanium rotary instruments: a multimethod research. J Endod. 2020;46(10):1485-94. http://doi.org/10.1016/j.joen.2020.07.016 PMid:32721485.

43. Purba R, Sonarkar SS, Podar R, Singh S, Babel S, Kulkarni G. Comparative evaluation of retreatment techniques by using different file systems from oval-shaped canals. J Conserv Dent. 2020;23(1):91-6. http://doi.org/10.4103/JCD.JCD_167_20 PMid:33223649.

44. Shemesh H, Roeleveld AC, Wesselink PR, Wu M-K. Damage to root dentin during retreatment procedures. J Endod. 2011;37(1):63-6. http://doi.org/10.1016/j.joen.2010.10.002 PMid:21146079.

45. Tamse A, Fuss Z, Lustig J, Kaplavi J. An evaluation of endodontically treated vertically fractured teeth. J Endod. 1999;25(7):506-8. http://doi.org/10.1016/S0099-2399(99)80292-1 PMid:10687518.

46. Ricks-Williamson LJ, Fotos PG, Goel VK, Spivey J, Rivera E, Khera S. A three-dimensional finite-element stress analysis of an endodontically prepared maxillary central incisor. J Endod. 1995;21(7):362-7. http://doi.org/10.1016/S0099-2399(06)80971-4 PMid:7499976.

47. Touré B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod. 2011;37(11):1512-5. http://doi.org/10.1016/j.joen.2011.07.002 PMid:22000453.

48. Nikkerdar N, Hatam R, Shahsavand L, Khavid A. The comparison of the rate of apical displacement in curved root canals using Neoniti and RaCe files by cone beam CT Scan. Braz Dent Sci. 2019;22(3):313-20. http://doi.org/10.14295/bds.2019.v22i3.1748.

49. Bozkurt DA, Terlemez A, Özcan M. Assessment of technical quality of 9562 endodontic cases treated by undergraduate students and endodontics specialists. Braz Dent Sci. 2021;24(1):9. http://doi.org/10.14295/bds.2020.v23i4.2240.

50. Jose J, Kasaragadda A, Siddique R. Comparison of postoperative pain reduction using continuous rotation glide path system with other methods of glide path creation-a systematic review. Braz Dent Sci. 2022;25(2):e2633. http://doi.org/10.4322/bds.2022.e2633.

Pradeep Solete
(Corresponding address)
Saveetha University, Saveetha Institute of Medical and Technical Sciences, Saveetha Dental College and Hospitals, Department of Conservative Dentistry and Endodontics, Chennai, India.
Email: pradeeps@saveetha.com

Date submitted: 2024 Mar 09
Accept submission: 2024 July 16