Original Article

Retreatability of NeoSEALER Flo obturated with warm vertical compaction versus single-cone technique using two different retreatment systems

Toka Kamaleldeen Elzanaty[1], Mohamed M. Elashiry[2,3], Abeer Hashem Mahran[3]

[1]Department of Endodontics, Faculty of Dentistry, Assiut University, Assiut, [3]Department of Endodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt, [2]Department of Endodontics, Dental College of Georgia, Augusta University, Augusta, GA, USA

Abstract

Aim: The aim of this study was to compare the retreatability of NeoSEALER Flo obturated with warm vertical compaction (WVC) and single-cone (SC) techniques using two different retreatment systems.

Materials and Methods: Thirty-two root canals were shaped and obturated with NeoSEALER Flo either in an SC obturation technique or a WVC technique. Samples were retreated using ProTaper retreatment or EdgeFile XR retreatment system. The percentage of remaining debris after retreatment was analyzed under a scanning electron microscope using ImageJ software. The time taken to reach full working length (WL) and induce patency was recorded.

Statistical Analysis: Statistical analysis was performed using an unpaired *t*-test and a one-way analysis of variance test.

Results: The percentage of remaining debris after retreatment was significantly higher in the SC technique than in the WVC technique, regardless of the retreatment system used. EdgeFile XR system removed more filling material than the ProTaper retreatment system, regardless of the obturation technique. The apical region showed significantly higher remaining debris than other regions in all groups. The WL and patency were achieved faster in the SC group, while in the WVC group, the EdgeFile XR system was faster.

Conclusions: The WVC technique showed better retrieval of the filling material; however, a longer time was taken for retreatment. EdgeFile XR system performed better in removing filling materials from inside the canals.

Keywords: Calcium silicate; remaining debris; retreatment; single cone; warm vertical compaction

INTRODUCTION

In recent years, different sealers have been introduced in the market, where calcium silicate sealers attracted much attention owing to their superior properties such as the fine particle size, the high sealing ability, chemical interaction with dentine, and the antimicrobial potential of these sealers.[1] The use of calcium silicate-based sealers with a single-cone (SC) obturation technique is becoming popular among clinicians due to the ease of handling, cost-effectiveness, less time-consuming, and the negative impact of heat application on some calcium silicate-based sealers when used with warm vertical compaction (WVC) technique.[2,3]

NeoSEALER Flo (Avalon Biomed, Houston, TX, USA) is a recently introduced premixed, bioactive resin-free calcium silicate-based sealer. It comprises tricalcium silicate, dicalcium silicate, calcium aluminate, calcium aluminum oxide (grossite), tricalcium aluminate, tantalite as a radiopacifier, and small amounts of calcium sulfate. As stated by the manufacturer, NeoSEALER Flo can withstand

Address for correspondence:
Dr. Toka Kamaleldeen Elzanaty,
Mahmoud Rashwan St., Assiut, Egypt.
E-mail: toka.k.elzanaty@dent.aun.edu.eg

Date of submission : 07.12.2023
Review completed : 31.12.2023
Date of acceptance : 02.01.2024
Published : 06.03.2024

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jcde

DOI: 10.4103/JCDE.JCDE_314_23

How to cite this article: Elzanaty TK, Elashiry MM, Mahran AH. Retreatability of NeoSEALER Flo obturated with warm vertical compaction versus single-cone technique using two different retreatment systems. J Conserv Dent Endod 2024;27:286-92.

high temperatures and thus could be utilized with both WVC and SC techniques.[4] According to the manufacturer, it has dimensional stability with <1% shrinkage and <0.1% expansion. It has a film thickness of <50 μm and a radiopacity of 6 mm, equivalent to aluminum.

The SC technique still needs further research to prevent any drawbacks from the higher volume of sealer to core material inside the root canal system, which may intensify the concerns already raised about calcium silicate-based sealers, such as the relatively long setting time, the high solubility, and the difficulty of the complete retrieval of these sealers from inside the root canals.[5]

Removing most of the filling material from inadequately prepared and filled root canal systems is essential to uncover remaining necrotic tissue or bacteria responsible for the persistent disease and enable thorough re-instrumentation and re-disinfection of the root canal system. Furthermore, root-filling remnants might reduce the adaptation and adhesion of sealers and cement used for posts.[6,7]

The study aimed to investigate the canal cleanliness following retreatment of NeoSEALER Flo that was obturated using either the WVC or the SC technique using two different retreatment systems. The null hypothesis is that there are no differences between WVC versus SC obturation of NeoSEALER Flo regarding canal cleanliness after retreatment with either the ProTaper retreatment system or EdgeFile XR system.

MATERIALS AND METHODS

Sample size calculation

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between tested groups. By adopting an alpha level of 0.05 and a beta of 0.2, i.e. power = 80%, and an effect size (f) of 0.567, the predicted sample size (*n*) for each group was 8, and the total number of samples was 32. Sample size calculation was performed using G*Power (Version 3.1.9.7, Franz Faul, Universität Kiel, Germany).[8]

Sample selection

Sixteen freshly extracted human permanent upper premolars with two separate roots were selected for this study. Teeth were collected from the outpatient clinic of the oral surgery department to be used in this study (total of 32 roots). The selected teeth were cleaned from calculus deposits with ultrasonic scalers and kept in 5.25 sodium hypochlorite (NaOCl) for 10 min to remove soft tissue and organic debris. Teeth were stored in 0.9% normal saline till the time of use. One periapical radiograph was taken for each tooth. Any tooth with severe curvature, immature apex, fracture, calcification, resorption, or previous endodontic treatment was excluded.

Sample preparation

After the access cavity was prepared for all the samples, the tooth length was determined by introducing K-file size 10 (Mani. Inc., Tochigi, Japan) into the canal till the tip of the file became visible from the apex. The working length (WL) was calculated by subtracting 0.5 mm from the tooth length.

After length determination, K-file size 10, followed by K-file size 15, was used to ensure canal patency and to create a glide path. All the canals were instrumented by the same type of nickel-titanium rotary files, Pepsi Gold Rotary files (Fanta Dental Materials Co., Ltd, Shanghai, China), according to the manufacturer's instructions so that all the canals had the same prepared final size 25/04 to WL. After each instrument, patency was checked, and the canals were irrigated using 3 mL of total concentration NaOCl with a plastic syringe and a 30-G side-vented needle (Endo-Eze Irrigator, Ultradent Products, South Jordan, UT, USA). As the final irrigation protocol, 2 mL of 17% ethylenediaminetetraacetic acid (EDTA) (Prevest DenPro Limited, Jammu, India) was used, followed by 2 mL of saline (sodium chloride), and then, 2 mL of NaOCl. Passive ultrasonic irrigation was used for 30 s with every irrigant. Finally, the canals were irrigated with 2 mL of saline solution and dried with paper points size 25/02.

Sample classification

The samples were randomly divided into two equal groups according to the obturation technique using GraphPad QuickCalcs random number calculator (https://www.graphpad.com/quickcalcs/randomize2).

Sixteen canals were obturated with NeoSEALER Flo using the WVC technique, and the other 16 were obturated with NeoSEALER Flo using the SC technique.

Root canal obturation

The sealer was used according to the manufacturer's instructions. For the SC group, the NeoSEALER Flo needle was inserted into the middle third of the WL and dispensed till the orifice, and then, the 25/04 master cone was inserted into the full WL. In the WVC technique, the apical third of the 25/04 master cone was covered with the NeoSEALER Flo and inserted into the canal to the full WL. A heated gun was used to cut the cone, leaving only 4 mm apically. The rest of the canal was filled with thermoplasticized gutta-percha (GP) to the orifice. Two periapical radiographs with different angulations (mesiodistal and buccolingual) were taken to confirm the homogeneity of the obturation of all teeth. After root canal obturation, the access cavities were sealed using direct adhesive restoration (SwissTEC

Composite, Coltène/Whaledent, Altstätten, Switzerland). All teeth were stored at 37°C and 100% humidity for 21 days to allow the complete set of sealers.[9]

Root canal retreatment procedure

The WVC and SC groups were re-accessed and randomly divided into two equal subgroups according to the retreatment files used. Root fillings were removed from eight canals using the ProTaper retreatment system, and the same was done for the EdgeFile XR retreatment system.

ProTaper retreatment system: According to the manufacturer's instructions, files were used at 500 rpm and 2.5 N/cm^2 torque. D1 file was used to remove the coronal third of the filling materials. D2 was used for the removal of the middle third of the canals. D3 was used for the removal of the apical third of the canal.

EdgeFile XR retreatment system: According to the manufacturer's instructions, files were used at 400 rpm and 3 N/cm^2 torque. R2 (15 mm tip size 25/08) was used to remove the coronal third of the filling material. R3 (length 19 mm tip size 25/06) was used to remove the middle third of the canals. R4 (length 23 mm tip size 25/04) was used to remove the apical third of the canal.

The canals were irrigated with NaOCl after using each file during the retreatment procedure. A total of 15 mL of 2.5% NaOCl was used. After each use, the debris was removed from the file using sterile gauze and examined to detect any distortion. Any file with any signs of distortion or unwinding was discarded immediately. Each instrument was used for the retreatment of four root canals. No additional instruments or solvents were applied. Patency was reestablished using K-file size and D-Finder size 10 files. Retreatment was considered complete when no filling material was detected on the instrument surfaces or inside the root canal or dentinal walls under magnification of ×5 loupes and confirmed by a periapical radiograph. As final irrigation, the root canals were irrigated with 2 mL of 17% EDTA and rinsed with 2 mL of saline. Then, 2 mL of 2.5% NaOCl was used, followed by 2 mL of saline. All irrigation solutions were dispensed by 5 mL. A disposable plastic syringe and 30-gauge side-vented needle placed 2 mm short of the predetermined WL. Every canal was dried with sterile paper points and sealed with composite resin. The same operator performed all the procedures.

Methods of analysis

Canal cleanliness evaluation

Teeth were prepared for scanning electron microscope (SEM) examination by performing grooves on each root from both the buccal and palatal surfaces. These grooves were used to cut every root longitudinally using a chisel. The optimum half was used for the examination. Each half was grooved at 2, 5, and 8 mm, representing the apical, middle, and coronal thirds. The specimens were mounted on an aluminum stub, sputter coated with gold, and observed under SEM; every sample was examined using SEM under ×1000 magnification. One image was made at the position of every groove. The total surface area covered by the residual debris was evaluated using ImageJ software. The percentage of debris area was calculated by residual debris area divided by total surface area multiplied by 100.[10]

Time taken to reach the full working length and patency

The total time from the use of the first retreatment file to reach the predetermined full WL and patency of each canal was recorded in seconds using a stopwatch.

Statistical analysis

Statistical analysis was done using GraphPad Prism (GraphPad Prism version 7.00 for Windows, GraphPad Software, La Jolla, California, USA). Data values were described as means ± standard deviation; unpaired *t*-test for analysis of two groups and one-way analysis of variance test for multiple groups with significance defined as $P < 0.05$; *post hoc* pair-wise comparisons were conducted using the Tukey test to compare multiple groups.

RESULTS

Root canal cleanliness evaluation

Apical level

The results showed that the ProTaper retreatment system had a significantly higher percentage of remaining debris than EdgeFile XR in both obturation techniques ($P < 0.05$). ProTaper retreatment system showed a significantly higher percentage of remaining debris when used to retreat SC obturated canals than WVC ($P < 0.0001$), while EdgeFile XR showed no statistically significant difference when any of the two obturation techniques were used [Figure 1a and d; $P > 0.05$].

Middle level

No statistically significant difference was found between the two retreatment files when used in SC obturated canals ($P > 0.05$). In the WVC group, the ProTaper retreatment system had a significantly higher percentage of remaining debris than the EdgeFile XR system ($P < 0.001$). The ProTaper retreatment system performed similarly in either SC or WVC obturated canals ($P > 0.05$), while the EdgeFile XR system removed more filling material from the WVC group than in the SC group [Figure 1b and d; $P < 0.01$].

Coronal level

Results showed that at the coronal level, there was no statistically significant difference in the percentage of

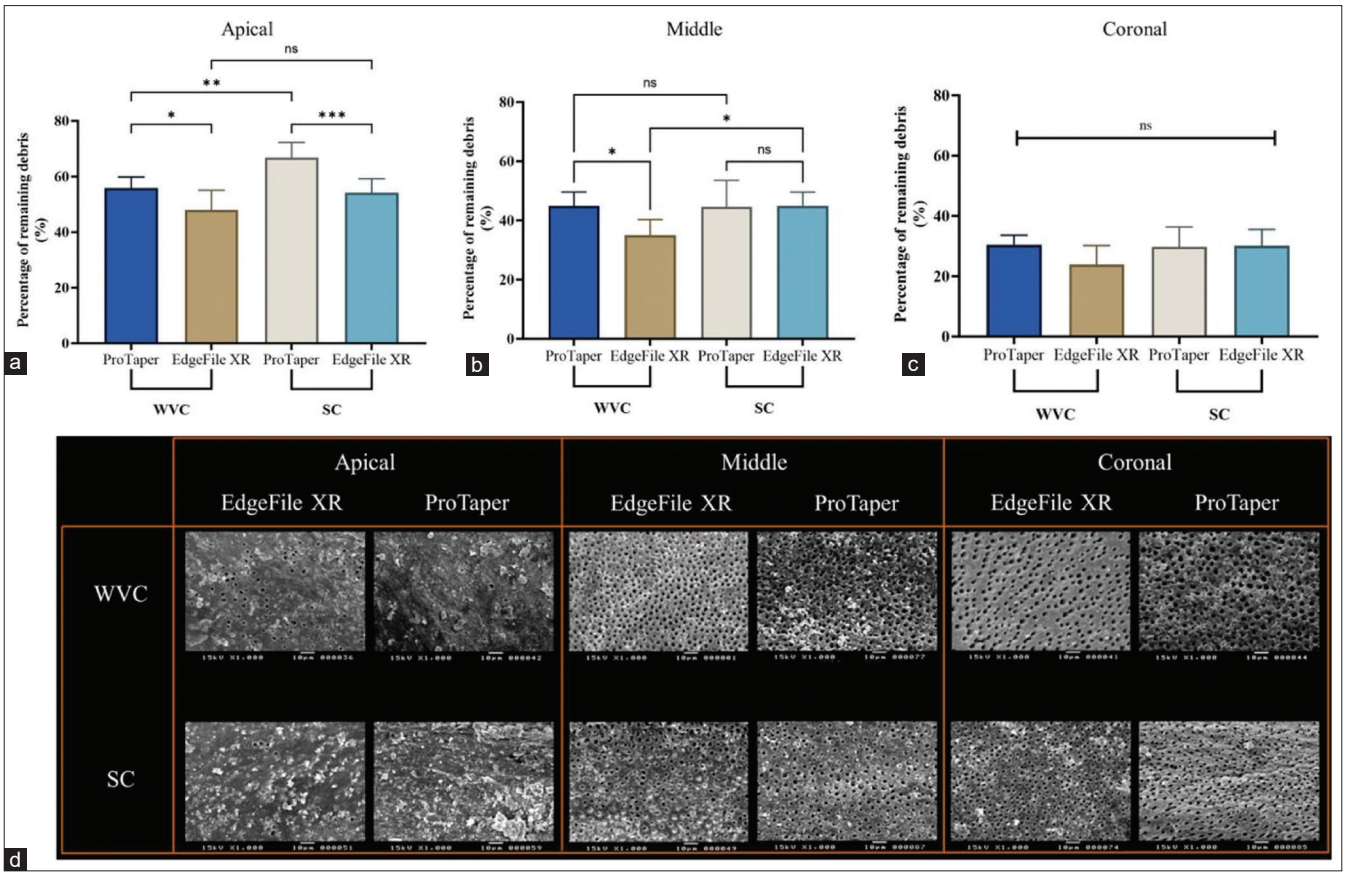

Figure 1: Bar chart showing the percentage of remaining debris after retreatment of canals obturated with warm vertical compaction and single-cone techniques using either ProTaper retreatment or EdgeFile XR system. (a) At the apical level, (b) Middle level, (c) Coronal level, (d) Scanning electron microscope representative images (magnification, ×1000) at the apical, middle, and coronal regions showing the remaining filling materials in canals obturated with NeoSEALER Flo in warm vertical compaction and single-cone techniques after retreatment using ProTaper retreatment and EdgeFile XR systems. Data presented as mean and standard deviation. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. WVC: Warm vertical compaction, SC: Single cone, ns: Nonsignificant

remaining debris between the two retreatment files when used in canals obturated with either WVC or SC technique [Figure 1c and d; $P > 0.05$].

The percentage of remaining debris was significantly higher in the apical third, followed by the middle third, and then the coronal region in all groups [Figure 2a and b; $P < 0.0001$].

Total remaining debris

The total percentage of remaining debris was significantly higher in the SC group regardless of the retreatment system used [Figure 2c; $P < 0.05$] and was higher in the ProTaper retreatment system regardless of the obturation technique used [Figure 2d; $P < 0.05$].

Time taken to reach the full working length and patency

The results showed that in the SC group, no statistically significant difference was found between the ProTaper retreatment system and EdgeFile XR system in the time taken to reach the full WL and patency ($P > 0.05$). While in the WVC group, the ProTaper retreatment system was significantly slower than the EdgeFile XR system to reach full WL [Figure 2e; $P < 0.01$].

DISCUSSION

This study compared the effectiveness of SC and WVC techniques on the ease of retreatment and canal cleanliness using two different retreatment systems. Premixed calcium silicate-based sealers have gained much attention owing to their ease of handling and uniform consistency. However, early versions of this type of sealer had major drawbacks when used in the WVC technique, as heat adversely affected their performance.[3] Consequently, the SC obturation technique was proposed with calcium silicate-based sealers.[11] In this study, NeoSEALER Flo was utilized as it is heat-resistant and deemed safe for the WVC obturation technique, as claimed by the manufacturer.[9]

Maxillary premolars with two separate roots were used for this investigation. Previous studies used single-rooted teeth as

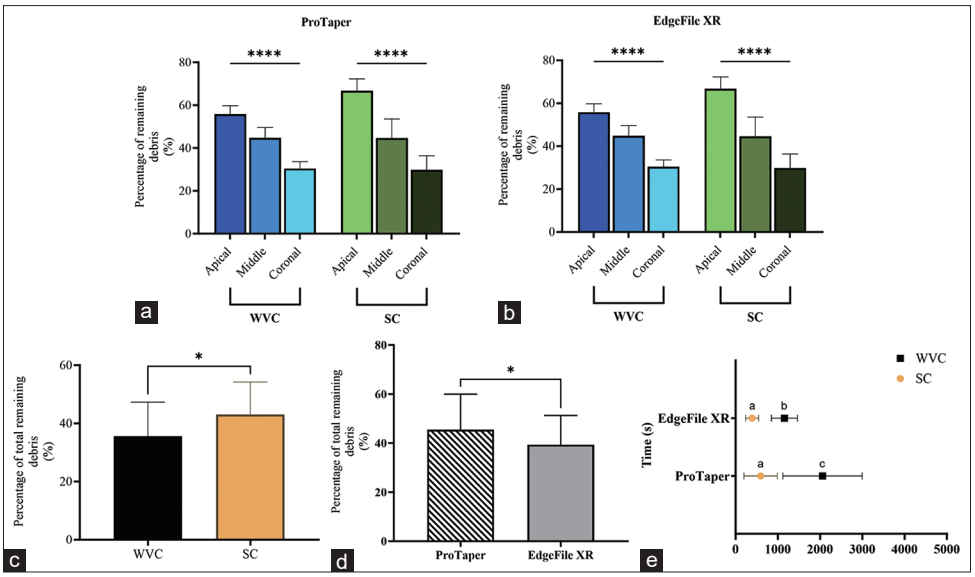

Figure 2: Bar chart showing the percentage of remaining debris in the different root canal regions after retreatment of canals obturated with warm vertical compaction and single-cone techniques. (a) Canals retreated with ProTaper retreatment system, (b) Canals retreated with EdgeFile XR system, (c) The total percentage of remaining debris in root canals was obturated with either warm vertical compaction or single-cone technique regardless of the retreatment system used, (d) The total percentage of remaining debris in root canals retreated with either ProTaper retreatment or EdgeFile XR system regardless of the obturation technique, (e) The line chart shows the time taken to reach the full WL and induce patency by ProTaper retreatment and EdgeFile XR systems in canals obturated with both techniques. Different letters indicate significant differences. Data presented as mean and standard deviation. *$P < 0.05$, ****$P < 0.0001$. WVC: warm vertical compaction, SC: Single cone

they are easier to prepare with minimal or no canal curvature. However, this study aimed to investigate the effect of the two obturation techniques on canal cleanliness after retreatment with different retreatment systems in a more challenging root canal morphology.[12,13] Furthermore, for standardization, the apical size preparation was performed up to size 25 taper 4, which is the final apical size in most retreatment kits. This preparation size is more convenient for the upper premolars with two separate roots than single-rooted teeth.[14]

After retreatment, most studies recommend additional preparation by files larger than the original files used in canal preparation.[15-17] This recommendation could not be followed as the aim was to compare the efficacy of the retreatment kits without any influence from external files. This approach was adopted by previous studies to accurately analyze the retreatment files in questions.[12,18] No solvents were used in the study to avoid introducing external materials that could affect the results. This ensured that the study relied solely on the effectiveness of retreatment files.[15]

The ProTaper retreatment system has been thoroughly discussed in different previous studies. The ProTaper Universal Retreatment system comprises three different files, each with specific dimensions and functions. The first file, D1, is 16 mm long, has a diameter of 0.3 mm, and a taper of 9%. It is designed to remove gutta-percha from the coronal third of the canal. The second file, D2, is 18 mm long, has a diameter of 0.25 mm, and a taper of 8%. It is used for the middle third of the canal. Finally, the third file, D3, is the longest at 22 mm, with a diameter of 0.2 mm and a taper of 7%, and it is intended for the apical third of the canal.

These files have a convex triangular cross section with variable taper, and they are made from conventional NiTi alloys that mainly consist of the austenite phase. This gives them superelasticity and shape memory, as well as high cutting efficiency, all of which are essential for successful retreatment procedures. The ProTaper universal retreatment instruments also have a specific flute design and rotary motion that tend to pull GP into the file flutes and direct them toward the orifice. In addition, the file blades have a negative cutting angle with no radial land, which exerts a cutting action on GP.[16,19] The EdgeFile XR retreatment system has been recently introduced for use in retreatment. EdgeFile XR retreatment files are made of an annealed heat-treated Ni-Ti alloy brand named FireWire™. This proprietary heat treatment provides higher flexibility with increased resistance to cyclic fatigue, characteristics that are compulsory in retreating curved canals. The system comprises four files: R1 with a length of 15 mm and taper of 12%, R2 with a length of 15 mm and taper of 8%, R3 with a length of 19 mm and taper of 6%, and R4 with a taper of 4% and a length of 23 mm. All the files have a nonactive tip with a diameter of 0.25 mm. All files have parabolic cross section.[14,20] To our knowledge, this is the first study comparing the ProTaper retreatment system to the EdgeFile XR system with different obturation techniques.

The efficacy of different retreatment files can be assessed by measuring the remaining filling materials. Digital radiography, Confocal laser scanning microscopy (CLSM), microcomputed tomography, and SEM have been used to evaluate the remaining filling materials. SEM was used in this study as the ultimate high magnification coupled with the lack of drawbacks of other techniques makes it supreme in the visualization of the canal space and consequently confirms the presence of remaining filling material after canal re-debridement.[15]

Nonsurgical endodontic retreatment is considered the first option in endodontic failure cases.[21] Achieving patency and thorough re-shaping and re-cleaning of failed root canal cases is the primary goal of nonsurgical retreatment procedures.[7,22] In this study, reaching the full WL and induction of patency was achieved in all specimens, indicating that retreatment of calcium silicate-based sealers is feasible.[23] However, a significant difference in time to achieve patency was found, and thus, the null hypothesis was rejected. In the WVC group, the time taken by the ProTaper retreatment system to reach the full WL and patency was higher than the EdgeFile XR files. This finding could be attributed to the file design and the variable taper in the ProTaper retreatment system.[24] The time taken to reach the full WL and achieve patency in the WVC group was significantly higher than in the SC group, regardless of the retreatment system used. This result suggests that the obturation technique greatly influences the time taken during retreatment. This finding is consistent with a previous study that found that groups obturated with WVC took longer to reach the full WL than groups obturated with the SC technique.[13] Kim *et al*. have proposed an alternating finding, suggesting that the WVC technique has a greater volumetric ratio of GP to the sealer. Thus, rapid retrieval could be achieved as GP is easier to remove than the sealer.[25]

The retreatment procedures could not completely remove the GP and sealer in any third of the canals, regardless of the obturation technique. This finding is in line with other studies, which confirmed that conventional retreatment techniques could not entirely remove the calcium silicate-based sealers from the confines of the root canals.[13,26,27] A comparison of canal cleanliness after retreatment showed that at the coronal level, there was no significant difference in the percentage of remaining debris regardless of the obturation technique or the retreatment files. This finding may be due to the accessibility and the higher effect of the irrigation solutions on the filling materials in the coronal thirds.[28,29] While in the middle third of the samples obturated with the WVC technique, the ProTaper retreatment system had a higher percentage of remaining debris than the EdgeFile XR system; thus, the null hypothesis is rejected in this part. Previous studies reported that the ProTaper retreatment system was inefficient in retrieving root canal filling material when used without supplemental instrumentation.[30,31] On the other hand, no difference was found in samples obturated by the SC technique between the EdgeFile XR system and the ProTaper retreatment system in the middle third. The higher percentage of sealer used in the SC obturation technique may be the reason for the similar performance of the two retreatment file systems.

In both groups of different obturation techniques, the ProTaper retreatment system had a higher percentage of remaining debris. This may be due to the difference in the tip cross section or the tip size of the final file of each kit. In the ProTaper file, D3 has a tip of size 20. However, in the edge group, the R4 file has a tip of size 25.[30]

Cleaning the apical third has always been challenging due to the smaller size of the canal in this area compared to other regions and the more anatomical complexities found apically. This may explain the higher percentage of remaining debris in the apical third in all the retreated canals.[32,33]

Regardless of the retreatment system used, the total remaining debris in canals obturated with SC was higher than in WVC obturated canals. This finding implies that the higher relative proportion of calcium silicate-based sealer inside canals obturated with the SC technique may complicate the retreatment process, especially when these sealers harden and are fully set.[34]

It is imperative to acknowledge that there were certain limitations to this *in vitro* study. The retreatment procedure was done 3 weeks after the initial treatment, which may not precisely mimic the clinical scenario as patients may seek endodontic retreatment years after the initial treatment. In addition, although the study did achieve patency and full WL in all cases, these outcomes may not be easily attainable in more complicated circumstances involving short fillings and ledges beyond the fillings. However, these limitations did not influence the results of this study.[9,35] Another potential limitation of the study is that the initial preparation size was relatively small, measuring only 25.04. Despite this, the investigation focused on the effectiveness of the retreatment files in removing sealers from within the canals according to the obturation techniques used without any additional preparation.

CONCLUSIONS

While the full WL and patency were attained more rapidly in SC obturated canals, the percentage of remaining debris after retreatment was higher in this group.

Using the SC technique with calcium silicate-based sealers may complicate the nonsurgical retreatment procedures

and adversely affect treatment outcomes as residual filling materials usually harbor bacteria responsible for disease persistence.

Acknowledgment

This study has been approved by the Research Ethics Committee of Ain Shams University (Cairo, Egypt) under clearance no. FDASU-Rec EM 112107.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E. Endodontic sealers based on calcium silicates: A systematic review. Odontology 2019;107:421-36.
2. Pedullà E, Abiad RS, Conte G, La Rosa GR, Rapisarda E, Neelakantan P. Root fillings with a matched-taper single cone and two calcium silicate-based sealers: An analysis of voids using micro-computed tomography. Clin Oral Investig 2020;24:4487-92.
3. Yamauchi S, Watanabe S, Okiji T. Effects of heating on the physical properties of premixed calcium silicate-based root canal sealers. J Oral Sci 2020;63:65-9.
4. Zamparini F, Prati C, Taddei P, Spinelli A, Di Foggia M, Gandolfi MG. Chemical-physical properties and bioactivity of new premixed calcium silicate-bioceramic root canal sealers. Int J Mol Sci 2022;23:13914.
5. Aminoshariae A, Primus C, Kulild JC. Tricalcium silicate cement sealers: Do the potential benefits of bioactivity justify the drawbacks? J Am Dent Assoc 2022;153:750-60.
6. Ruddle CJ. Nonsurgical retreatment. J Endod 2004;30:827-45.
7. Fleming PS, Dermody J. Endodontic retreatment: Explaining success rates and illustrated cases. J Ir Dent Assoc 2003;49:95-100.
8. Faul F, Erdfelder E, Lang AG, Buchner A. G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175-91.
9. Carrillo CA, Kirkpatrick T, Freeman K, Makins SR, Aldabbagh M, Jeong JW. Retrievability of calcium silicate-based root canal sealers during retreatment: An *ex vivo* study. J Endod 2022;48:781-6.
10. Horvath SD, Altenburger MJ, Naumann M, Wolkewitz M, Schirrmeister JF. Cleanliness of dentinal tubules following gutta-percha removal with and without solvents: A scanning electron microscopic study. Int Endod J 2009;42:1032-8.
11. Angerame D, De Biasi M, Pecci R, Bedini R. Filling ability of three variants of the single-cone technique with bioceramic sealer: A micro-computed tomography study. J Mater Sci Mater Med 2020;31:91.
12. 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;40:543-6.
13. Yang R, Tian J, Huang X, Lei S, Cai Y, Xu Z, *et al*. A comparative study of dentinal tubule penetration and the retreatability of EndoSequence BC sealer HiFlow, iRoot SP, and AH plus with different obturation techniques. Clin Oral Investig 2021;25:4163-73.
14. Özlek E, Gündüz H. Effectiveness of different rotary file systems in removing the root canal filling material: A micro-computed tomography study. J Dent Res Dent Clin Dent Prospects 2021;15:273-8.
15. Bernardes RA, Duarte MA, 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;49:890-7.
16. Jorgensen B, Williamson A, Chu R, Qian F. The efficacy of the WaveOne reciprocating file system versus the ProTaper retreatment system in endodontic retreatment of two different obturating techniques. J Endod 2017;43:1011-3.
17. Kaloustian MK, Nehme W, El Hachem C, Zogheib C, Ghosn N, Mallet JP, *et al.* Evaluation of two shaping systems and two sonic irrigation devices in removing root canal filling material from distal roots of mandibular molars assessed by micro CT. Int Endod J 2019;52:1635-44.
18. Hassan R, Elzahar S. Cleaning efficiency of XP finisher, XP finisher R and passive ultrasonic irrigation following retreatment of teeth obturated with TotalFill HiFlow bioceramic sealer. Eur Endod J 2022;7:143-9.
19. Beasley RT, Williamson AE, Justman BC, Qian F. Time required to remove guttacore, thermafil plus, and thermoplasticized gutta-percha from moderately curved root canals with protaper files. J Endod 2013;39:125-8.
20. Varghese E, Awasthi N, Kakarla P, Mailankote S, Mishra D, John NK. Evaluation of root dentin damage during retreatment procedure using various engine-driven retreatment file systems-a micro-CT study. J Pharm Bioallied Sci 2023;15:S434-7.
21. Torabinejad M, White SN. Endodontic treatment options after unsuccessful initial root canal treatment: Alternatives to single-tooth implants. J Am Dent Assoc 2016;147:214-20.
22. Das S, De Ida A, Das S, Nair V, Saha N, Chattopadhyay S. Comparative evaluation of three different rotary instrumentation systems for removal of gutta-percha from root canal during endodontic retreatment: An *in vitro* study. J Conserv Dent 2017;20:311-6.
23. Donnermeyer D, Bunne C, Schäfer E, Dammaschke T. Retreatability of three calcium silicate-containing sealers and one epoxy resin-based root canal sealer with four different root canal instruments. Clin Oral Investig 2018;22:811-7.
24. Uezu MK, Britto ML, Nabeshima CK, Pallotta RC. Comparison of debris extruded apically and working time used by ProTaper universal rotary and ProTaper retreatment system during gutta-percha removal. J Appl Oral Sci 2010;18:542-5.
25. Kim SR, Kwak SW, Lee JK, Goo HJ, Ha JH, Kim HC. Efficacy and retrievability of root canal filling using calcium silicate-based and epoxy resin-based root canal sealers with matched obturation techniques. Aust Endod J 2019;45:337-45.
26. Baranwal HC, Mittal N, Garg R, Yadav J, Rani P. Comparative evaluation of retreatability of bioceramic sealer (BioRoot RCS) and epoxy resin (AH Plus) sealer with two different retreatment files: An *in vitro* study. J Conserv Dent 2021;24:88-93.
27. Kakoura F, Pantelidou O. Retreatability of root canals filled with gutta percha and a novel bioceramic sealer: A scanning electron microscopy study. J Conserv Dent 2018;21:632-6.
28. Jayasenthil A, Sathish ES, Prakash P. Evaluation of manual and two-rotary niti retreatment systems in removing gutta-percha obturated with two root canal sealers. ISRN Dent 2012;2012:208241.
29. Ghivari S, Kubasad G. Root canal debris removal using different irrigating needles: An SEM study. Indian J Dent Res 2011;22:659-63.
30. Akshay VA, Srirekha A, Reddy J, Champa C, Shetty A, Srinivasan A. Evaluation of the efficacy of TruNatomy, ProTaper retreatment, and RaCe file systems in retreatment of moderately curved mandibular molars: An *in vitro* study. J Conserv Dent 2023;26:383-7.
31. Gu LS, Ling JQ, Wei X, Huang XY. Efficacy of ProTaper universal rotary retreatment system for gutta-percha removal from root canals. Int Endod J 2008;41:288-95.
32. Shrestha S, Karki S, Agrawal N, Vikram M, Singh V, Shrestha A. Prevalence of different types of apical root canal morphology and their treatment recommendations in an institute. JNMA J Nepal Med Assoc 2018;56:616-20.
33. Athkuri S, Mandava J, Chalasani U, Ravi RC, Munagapati VK, Chennareddy AR. Effect of different obturating techniques and sealers on the removal of filling materials during endodontic retreatment. J Conserv Dent 2019;22:578-82.
34. Zhang W, Liu H, Wang Z, Haapasalo M, Jiang Q, Shen Y. Long-term porosity and retreatability of oval-shaped canals obturated using two different methods with a novel tricalcium silicate sealer. Clin Oral Investig 2022;26:1045-52.
35. Lee T, Kahm SH, Kim K, Yang S. The retrievability of calcium silicate-based sealer during retreatment and the effectiveness of additional passive ultrasonic irrigation: A microcomputed tomographic study. Scanning 2022;2022:3933305.