ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
March2025 • Vol. 37

Retreatability of bioceramic and resin-based root canal sealers using XP shaper rise: An in vitro Study

Sondos Sayed Abdelawad Abdalla[1], Muhammed Abouel Seoud[2], Shehabeldin Mohamed Saber[1,2,3]

Aim: The purpose of this study was to investigate *in-vitro* the retreatability of premixed calcium-silicate-based sealer versus resin-based sealer when combined with gutta-percha using the single-file system XP-endo Rise.
Materials and methods: 26 canals in typodont acrylic Nissin teeth were instrumented with E-flex blue rotary instruments up to size 0.35mm and taper of 4%. Root canals were divided into two groups, obturated using either hydraulic condensation technique with a bioceramic sealer (n=13) or continuous wave of compaction (CWC) technique with a resin-based sealer (n=13). The retreatment procedure was done for both groups using the XP-endo Rise instruments. The time required to complete the retreatment procedures was recorded in seconds. Cone beam computed tomography (CBCT) was used to assess the obturation material left after retreatment. Retreatment time results were analyzed statistically using an independent t-test, and number of canals with total filling material removal were compared between groups using Fisher's exact test, with a significance level (α) set to 0.05.
Results: Patency was achieved in all samples. The retreatment time was longer for canals filled with the bioceramic-based sealer compared with the resin-based sealer ($p < 0.05$). However, the total number of canals with filling remnants were significantly more in the resin-based sealer group compared to the bioceramic-based sealer group, ($p < 0.05$).
Conclusion: The bioceramic sealer used with the hydraulic condensation technique was effectively retreated, leaving no residual material, even though the retreatment time demonstrated a noticeably longer duration compared to the resin-sealer used with the CWC technique.

Keywords: Bioceramic sealer; CBCT; Retreatment; Resin sealer; XP-endo Rise.

1. Department of Endodontics, Faculty of Dentistry, The British University in Egypt, El-Sherouk City, Egypt.
2. Department of Endodontics, Ain Shams University, Cairo, Egypt.
3. Dental Science Group, Health Research Centre of Excellence, The British University in Egypt, El-Sherouk City, Egypt
Corresponding author: Shehabeldin Mohamed Saber , email: Shehabeldin.saber@bue.edu.eg

Introduction

The main objectives of root canal retreatment are to eliminate all root canal filling materials, restore apical patency, and ensure efficient cleaning and shaping of the root canal system.[1,2] However, achieving such objectives can be anatomically challenging, technically time consuming, and sometimes the total removal of root canal filling remnants is not achievable. This is very important as it can compromise treatment outcomes, especially if filling remnants harbor or prevent access to microbial biofilms. [3] Additionally, remaining debris can hinder the adherence of the new root canal filling to radicular dentin, potentially leading to failure. [4]

Traditionally, removal of root canal filling materials can be achieved using either manual or engine-driven instruments that are manufactured from stainless steel or nickel-titanium alloys [5], and used in different kinematics. [6] The XP-endo Shaper (XPS) (FKG Dentaire SA, Switzerland) is made of specific alloy (MaxWire, Martensite-Austenite Electropolish-flex), with an ISO #30 tip and a 0.01 taper at room temperature. According to the manufacturer, this particular alloy's properties allow the instrument to expand to a tip size of 30 and 0.04 taper when exposed to body temperature, resulting in more contact with the root canal walls. The file snake-like design creates a corkscrew effect, encircling and removing gutta-percha from canal walls instead of burnishing it. [7] Previous studies have shown the usefulness of this instrument in retreatment. [8] The XP-endo Rise (FKG Dentaire SA, Switzerland)is the latest generation of adaptable XP shaper lines offering the same features as previous model, equipped with a new tip with six facets instead of three in the older version, that has been shown to boost predictability and control, enhancing efficiency, flexibility and cyclic fatigue resistance. This shaper also simplifies retreatment procedure, adjust to canal anatomy, improves debris removal, disinfection, and decrease retreatment time. [9]

Gutta-percha is the most often utilized material for root canal filling, along with different sealers. Sealers can be classified by their chemical composition into zinc oxide eugenol-based, epoxy resin-based, silicon-based, methacrylate resin-based, and calcium silicate-based or biocaeramic (BC) sealers. Epoxy resin-based sealers are considered the gold standard in endodontics.[10] They have developed popularity over many years because of their positive physicochemical properties and antibacterial activity, however, when extruded from the apical foramen, it does not easily resorb and can cause a short-term inflammatory reaction. [11] Based on a new concept of hydraulic condensation, the so-called “BC sealers” offer a viable alternative to the current gold standard epoxy resin-based sealers. [12] BC sealers are increasingly being used because of their multiple merits including biocompatibility, bioactivity, hydrophilicity, sealing ability, exceptional fluidity, radio-opacity, as well as their chemical and thermal stability. [13–15] The application technique of BC sealers is simple and quick; therefore, it has been quickly adopted by many clinicians. [16] The rising use of BC sealers has necessitated the implementation of new retreatment protocols for BC-obturated cases. [17] Some authors reported challenges in retreatment procedure of BC sealers, including increased retreatment time, failure to achieve apical patency, and inability to fully remove the sealer as compared to resin sealer. [5] One of the characteristics of the optimum root canal sealer that Grossman mentioned is its ease of removal from the canal when required. [18] Thus, this study was designed to compare in-vitro the retreatability of CeraSeal (CS) (Meta Biomed Co., Cheongju, Korea) which is a BC sealer versus AD-Seal (Meta Biomed Co., Cheongju, Korea) which is a resin-based one, using the

XP endo Rise. Several factors have been used to measure the retreatability of sealers, including the ability to restore the working length (WL) and patency, the time to achieve the patency, and the amount of residual root canal filling material or sealer. [19] Therefore residual gutta-percha in the root canal space was assessed using cone beam computed tomography (CBCT), which has been proved to be a reliable method for such assessments based on prior published articles. [20,21] The null hypothesis tested is that there is no difference in retreating root canals filled using either sealer as regards the retreatment time or the amount of filling remnants.

Materials and methods

Ethical approval, Sample size calculation and Grouping

This study had an ethical clearance from the research ethics committee at the Faculty of Dentistry, the British University in Egypt, with the approval number (FD BUE REC 23-020) as it did not include any human or animal subjects. A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis. By adopting an alpha (α) level of (.05), a beta (β) of (.05), i.e. a power of 95%, and an effect size (f) of (1.5217) calculated based on the results of Azim et al. (2018) [20], the minimum required total sample size (n) was calculated to be 26 teeth (13 per group). Sample size calculation was performed using G*Power version 3.1.9.7 (Heinrich-Heine-University, Düsseldorf, Germany). [22] Teeth were categorized into two groups: BC and resin. In the BC group, canals were obturated using CS while in the resin group, canals were obturated using AD-Seal.

Teeth and model

26 canals of typodont acrylic Nissin teeth with root canal (Endodontic Tooth Model [A12A-200]) Were collected and fitted alternatively in a typodont Nissin study model (Nissin Dental Products, Inc., Kyoto, Japan) (Figure 1**Error! Reference source not found.**), each group of sealers had 13 canals.

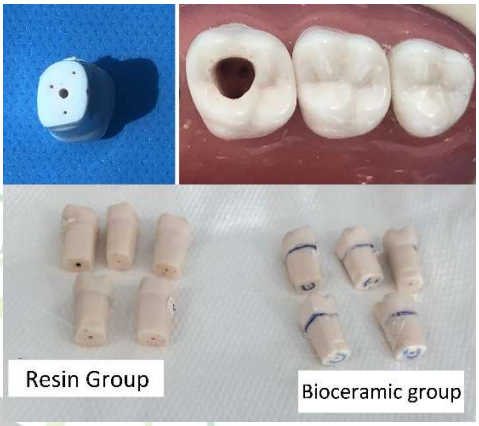

Figure 1: Nissin teeth with root canals.

Root canal sealers

In this study, we investigated the retreatability of epoxy resin-based sealer: AD Seal (Meta Biomed,Cheongju, Korea) and bioceramic-based sealer: CeraSeal (CS; Meta Biomed,Cheongju, Korea). Table 1 shows the chemical compositions of the root canal sealers examined in this study.

Table 1: Composition of bioceramic and resin-based sealers

Name of sealer	Manufacturer	Format	Composition
Ceraseal (CS)	Meta Biomed	Single syringe	Zirconium dioxide, Tricalcium silicate, Dicalcium silicate, Tricalcium aluminate and thickening agent[23]
AD-Seal	Meta Biomed	Dual syringe	*Base:* Epoxy oligomer resin, Ethylene glycol salicylate, Calcium phosphate, Bismuth subcarbonate, Zirconium oxide. [24] *Catalyst:* Poly aminobenzoate, Triethanolamine, Calcium phosphate, Bismuth subcarbonate, Zirconium oxide, Calcium oxide.[24]

Root Canal Preparation and Obturation

Access preparation was done using round diamond burs. Size 15 K-file (Dentsply

Sirona Maillefer, Ballaigues, Switzerland) was used to measure the working length, stopping 0.5 mm short of the apical foramen. Working length was verified by periapical radiographs. E-flex blue heat-treated control memory nickel titanium rotary instruments (Eighteeth, Changzhou City, Jiangsu Province, China) were used to instrument the canals, until a final dimension of an apical diameter of 0.35 mm and a taper of 4% at 350 rpm and torque of 2 N.cm using X-Smart Endo Motor (Dentsply Sirona, Charlotte, USA).

A 30-gauge double side-vented needle (IrriFlex; Produits Dentaires, Vevey, Switzerland) was used to irrigate the canal with 2ml water after each file and 5ml water as a final irrigation of the canal. [23] Apical patency was maintained with size 10 K-file. The canals were finally dried with paper points for the resin-based sealer group, whereas Cerkamed aspirator (Cerkamed Wojciech Pawlowski, Poland) was used to dry canals in the BC group to preserve some moisture to initiate the setting. [24]

For resin-based sealer group continuous wave compaction (CWC) technique was employed, starting with a 35/0.04 tapered gutta-percha cone which was placed 0.5mm short of the working length. The tip of the master gutta-percha cone was coated with sealer and placed in the canal. System B heat source Eighteeth fast pack (Eighteeth, Changzhou City, China) was used at 200°C where a medium-sized tip (size 50/0.05) was placed with a rubber stop that was set at 4 mm short of the working length. The tip was held in position for 10 seconds, then activated for 1 second, and removed from the canal, keeping the apical 4 mm of filling material. After removing the coronal and middle portions of the fillings, packing of the apical part was done using Buchanan hand pluggers (Kerr U.K.) (size 50). A softened gutta percha was injected in 3mm increments into the canal using a cordless gutta percha Eighteeth fast fill obturation system (Eighteeth, Changzhou City, China) with #25-gauge needle which was set on 200°C. Each gutta percha increment of 3mm was compacted using Buchanan hand pluggers. The canal was backfilled until canal orifice.

For bioceramic sealer (Ceraseal (CS)) (Meta Biomed Co., Cheongju, Korea) group hydraulic condensation technique was employed with a single matched gutta-percha cone 35/0.04 and bioceramic sealer. Sealer paste was injected using its exclusive syringe into the coronal third of the canal, then the gutta-percha cone was coated with sealant and inserted into the canal till it reached the working length. At the level of canal orifice, excess gutta percha was severed using heat source Eighteeth fast pack and compacted with hand plugger using Buchanan pluggers, while keeping vertical compaction pressure for few seconds which was followed by cleaning the excess sealer with air water syringe. Finally wet cotton was placed in the pulp chamber as a source of hydration to start setting reaction.

The access cavities were temporized with Cavit G (3M ESPE, Seefeld, Germany). To enable the sealers to completely set, samples were incubated at 37°C in a humidified environment for either 7 days in the AD-Seal group or 30 days in the Ceraseal group. [25,26]

Retreatment Procedures

Retreatment protocol was standardized for all groups. D-Race 1 (DR1) (30/0.10) (FKG, La Chaux de Fonds, Switzerland) was used to remove the first 3 mm of the filling material from the canal operating at 1000 rpm and 1.5 Ncm using X-Smart Endo Motor, then one drop of Eucalyptol gutta percha solvent (PPH Cerkamid, Poland) was placed in the coronal space for 1 minute to soften the obturating material in both groups. For the next step, the

tip of XP-endo Rise was placed into the prepared space in the gutta percha, disengage slightly and start the motor at 1200 rpm and 1 Ncm torque, pecking motion was used until the XP-endo Rise Shaper´s tip engaged the gutta-percha, then light pressure was applied to help advance the XP-endo Rise down the canal until working length, and the canal was irrigated with water using 30-gauge double side-vented needle (IrriFlex; Produits Dentaires, 1800 Vevey, Switzerland). Upon reaching the working length, an additional 15 vertical gentle strokes to the full working length were done using XP endo rise file to allow removal of any remaining obturation material as recommended by the manufacturer retreatment protocol.[9] Patency was verified with a #15 hand file .The overall time needed for the retreatment procedure was calculated using a stopwatch. This timescale, was defined as the duration of time from the moment the instruments were first inserted into the canal until patency was gained with additional 15 vertical gentle strokes, excluding the time needed for irrigation and instrument changes. To avoid the inter-operator variables all root canal instrumentation and retreatment operations were done by an experienced single operator. Workflow of retreatment procedure is summarized in (**Error! Reference source not found.**).

Analysis of the Remaining Root Canal Filling Material

CBCT scan was performed post obturation and post retreatment procedure by means of Planmeca CBCT machine (Helsinki, Finland) using 12×8 cm field-of-view and the following parameters (voxel size 150 µm; 110 kV; 32 mA). CBCT scan was imported as a DICOM file into 3D Slicer imaging platform (v 4.8.1, https://www.slicer.org). Subsequently, typodont teeth with canals segmentation was performed using segment editor tab, where the imported DICOM data was added. And semi-automated segmentation technique was employed and manual refinement with minimum and maximum threshold range 1756.10 and 3095, respectively, which gave the most accurate identification of obturation material outline. This was followed by applying show 3D icon tab, to create 3-Dimentional image of segmented obturation material left in the canal. After segmentation process was completed, scissor icon was used to measure each canal remained obturation material volume (mm3) separately, using region of interest (ROI) tab to help in accurately isolating the targeted canal which represented the apical foramen to the cement-enamel junction. Subsequently, segment statistics was selected from quantification tab, where an automated method computed the remaining obturation volume in cubic millimeter (mm^3). [27] To allow for accurate comparisons, all specimens were segmented and using same process.

Data collection and statistical analysis

Data acquired from retreatment time measurements were represented as a continuous variable. For normally distributed data, descriptive statistics were reported in the form of mean and standard deviation. The Shapiro-Wilk test and modified Levene's test were both used to assess the data normality and homogeneity assumptions. If none of these assumptions were violated, an independent samples t-test was used to compare the two groups. A p-value of < 0.05 indicated statistical significance. We calculated a confidence interval of 95% for all of the parameters. The number of cases with total filling material removal was compared between groups using Fisher's exact test. Statistical analyses were conducted using Jamovi software (Version 2.4; https://www.jamovi.org). [28]

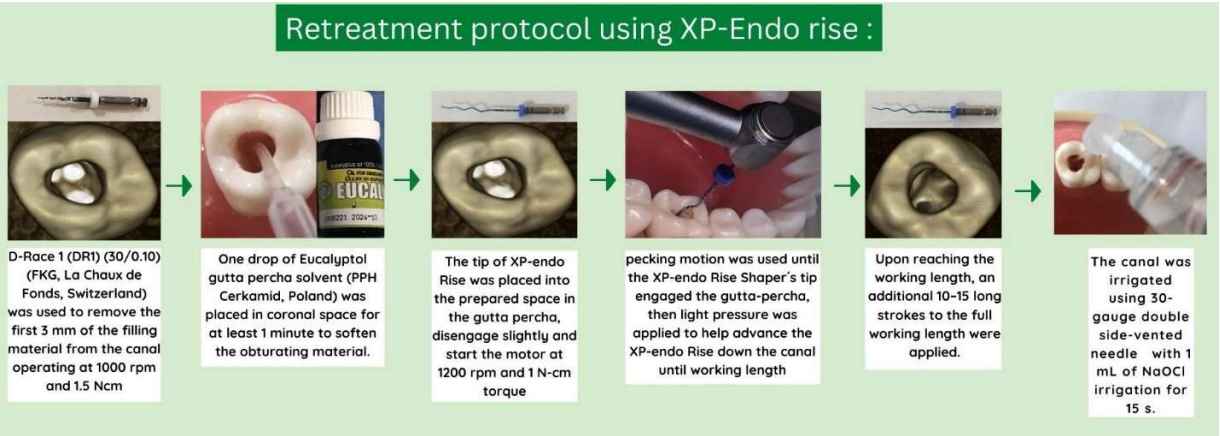

Figure 2: Summary of retreatment protocol using XP Endo Rise.

RESULTS

Patency was gained in all canals in both groups, and there was no incidence of perforation or canal transportation. Results for the retreatment time were parametric and followed a normal distribution. There was a significant effect for the type of sealer on retreatment time ($p < 0.05$), with advantage of the resin-based sealer obturation over the BC sealer (

Table). On the other hand, the BC group showed significant efficiency in filling material removal with no remnants of the obturation material in all samples compared to the resin-based sealer ($p < 0.05$) (

Figure ,**Error! Reference source not found.**).

Table)(

Type of sealer	Mean (SD)	Minimum time	Maximum time	Difference (95% CI)	Shapiro-wilk test (P)	P-value
Biocearmic (n= 13)	67.6 (15.9)	36	93	26.2 (15.2, 37.3)	0.672	<.001*
Resin (n= 13)	41.4 (10.9)	28	62		0.152	

SD: standard deviation, CI: confidence interval, *P is statistically significant at < 0.05.

Table 2: Descriptive for the Retreatment Time (Seconds)

	Patency time/seconds

Table 3: Number of cases with the presence or absence of remaining root canal filling material after retreatment using Fisher's exact test.

Presence or absence of remaining root canal filling material after retreatment			
Type of sealer	Absence of remaining material n (%)	Presence of remaining material n (%)	(P-value) Total (n= 26)
Biocearmic	13 (100%)	0 (0.0%)	0.015*
(n= 13)			
Resin (n= 13)	7 (53.8%)	6 (46.2%)	

*P is statistically significant at < 0.05. n: number of canals.

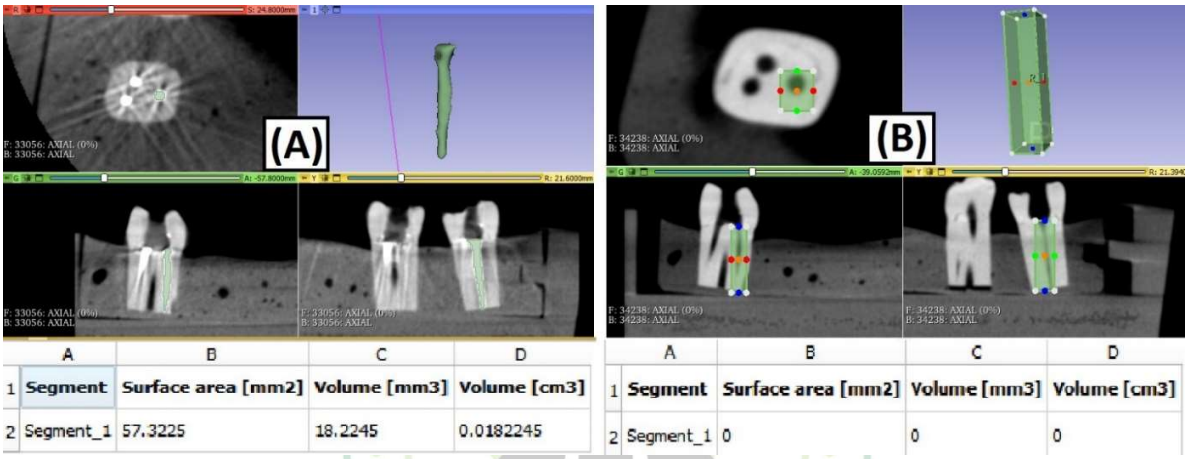

Figure 3: Assessment of obturation volume/mm^3 and remaining material volume/mm^3 using 3D Slicer in canal filled with bioceramic Sealer of a representative sample, demonstrates the region of interest in axial, coronal, and sagittal slices, in addition to the 3D image with the measured volume/mm^3: (A) Obturation volume/mm^3, (B) Remaining material volume/mm^3, no remnant material in the canal.

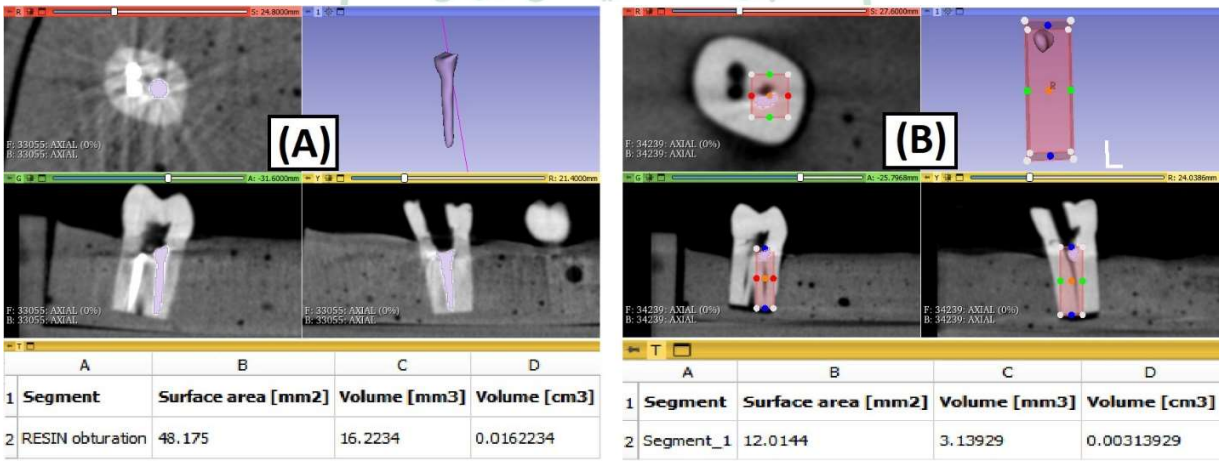

Figure 4: Assessment of obturation volume/mm^3 and remaining material volume/mm^3 using 3D Slicer in canal filled with resin Sealer of a representative sample, demonstrates the region of interest in axial, coronal, and sagittal slices, in addition to the 3D image with the measured volume/mm^3: (A) Obturation volume/mm^3, (B) Remaining material volume/mm, small fragments of remnant material are scattered in the coronal thirds.

Discussion

Calcium silicate-based materials are generally recognized for their antibacterial properties, bioactivity, and biocompatibility. [15,29] The same is true for the BC sealers. However, data regarding the retrievability of such sealers from root canals in case of primary treatment failure are limited. [30] Ideally, all existing filling materials must be removed completely to achieve the best cleaning and shaping results in retreatment cases. [7] Otherwise, they can obstruct the apical foramen and cause loss of apical patency in some cases. [31,32]

obturation and after retreatment. Methods used to assess the effectiveness of removal of root canal filling materials during retreatment include digital radiography [36], confocal microscopy [37], scanning electron microscopy [37], optical microscopy [38], CBCT [20], and micro-computed tomography (Micro-CT). Micro-CT is now a widespread imaging tool in endodontic radiology [15], using microfocus spot x-ray sources and high-resolution detectors, enables acquisition of the images with voxel sizes ranging from 5 to 50 mm. However, micro-CT devices are costly and need longer scanning and reconstruction durations than CBCT. Additionally, due to the high radiation dose, in vivo scanning is currently not practicable. Compared to micro-CT, CBCT which was used in the current study has acceptable cost, shorter scan time, lower radiation dose, and faster data collection. [39,40]

The XP endo Rise file showed its best performance when it was introduced as a new file in the canal for retreatment. it worth

Choices during this *in-vitro* study prioritized reducing confounding factors. The anatomic structure of the canal had a greater influence on the time of retreatment and the amount of residual filling material.[33,34] Therefore, the use of standardized root canal replicas aided to standardize the canal anatomy. They were also chosen because they had a Hounsfield unit, which is comparable to natural dentine and can be detected in CBCT. [35]

To simulate the clinical protocol, a solvent was used to aid in the softening of gutta percha. All teeth were CBCT scanned after noting that the XP endo rise files exhibited a buckling effect when they were used for retreatment in more than one canal which led to file fatigue and separation. Buckling is characterized by an abrupt lateral deflection of an instrument when a compressive force overcomes its resistance. [41] Instruments with low buckling resistance may experience elastic or plastic distortion, limiting apical advancement in the canal.

According to our findings, the null hypothesis is rejected as retreatment duration showed a statistically significant difference between the two groups with a superiority for retreating canals filled using the resin-based sealer. Yet, they were associated with significantly more filling remnants ($P < 0.05$). Resin-based sealers used in continuous wave compaction may have a higher volumetric ratio of gutta-percha compared to bioceramic-based sealers used with single cone technique. Additionally, gutta-percha has a higher removal efficiency than sealers. [42] This can justify why the

bioceramic group showed a longer retreatment time than the resin group.

Our results agree Agrofiati et al.[43], Romeiro K et al.[44] and Alsubait et al. [45] who all reported more retreatment time for the BC sealer-based obturations in comparison to the resin-based sealer ones. As well as studies by Donnermeyer et al.[30], Rajda et al.[3], Alsubait et al.[45] and Liu et al.[46] who reported that BC sealers outperformed resin sealers in terms of retreatability, leaving less sealer residues.

Contrary to our findings, Kim et al. [33] using resin and BC sealers and a single obturation technique (CWC), and Athkuri et al. [47] using different obturation techniques showed no significant difference in retreatment efficiency between the resin and BC sealer in terms of retreatment time or residual material.

Limitations of this study include being performed only on straight canals, absence of dentin as an adhesion substrate [48] as well as the absence of dentin moisture essential for hydration of BC sealers. Yet, previous research which was performed in Dentalike resin teeth with root canals simulating maxillary molars showed complete setting of bioceramic sealer when the sample was stored at 37C for 4 weeks.[25] Thus, future studies should focus on exploring the retreatment efficiency of clinical cases with more complex root canal morphology.

Conclusion

Within the limitation of the current study, the following can be concluded:

1- BC sealers are negotiable for simple root canal anatomy. However, they might require a longer retreatment duration than resin-based sealers.
2- XP-endo rise was efficient in the retreatment if used as a single-use file to avoid its fatigue or its low buckling resistance.

Funding information

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

Data availability

Data available upon reasonable request from the corresponding author.

Ethics approval and consent to participate

This study had an ethical clearance from the research ethics committee at the Faculty of Dentistry, the British University in Egypt, with the approval number (FD BUE REC 23-020) as it did not include any human or animal subjects.

Competing interests: None

References

1. Grischke J, Müller-Heine A, Hülsmann M. The effect of four different irrigation systems in the removal of a root canal sealer. Clinic Oral Investigation. 2014 Sep 1;18(7):1845–51.
2. Fahim MM, Saber SEM, Elkhatib WF, Nagy MM, Schafer E. The antibacterial effect and the incidence of post-operative pain after the application of nano-based intracanal medications during endodontic retreatment: a randomized controlled clinical trial. Clinical Oral Investigations. 2022 Feb 1;26(2):2155–63.
3. Rajda M, Miletić I, Baršić G, Krmek SJ, Šnjarić D, Baraba A. Efficacy of reciprocating instruments in the removal of bioceramic and epoxy resin-based sealers: Micro-ct analysis. Materials. 2021 Nov 1;14(21).
4. Eldeeb IM, Nawar NN, Saber SM, Hassanein EES, Schäfer E. Smear layer removal and sealer penetration with different tapers after using photon-initiated photoacoustic streaming technique. Clinical Oral Investigations [Internet]. 2021 Aug 1 [cited 2024 Oct 21];25(8):5025–32. Available from: https://link.springer.com/article/10.1007/s00784-021-03813-y
5. Arul B, Varghese A, Mishra A, Elango S, Padmanaban S, Natanasabapathy V. Retrievability of bioceramic-based sealers in comparison with epoxy resin-based sealer assessed using microcomputed tomography: A systematic review of laboratory-based studies. Vol. 24, Journal of Conservative

Dentistry. Wolters Kluwer Medknow Publications; 2021. p. 421–34.
6. Saber SM, Alfadag AMA, Nawar NN, Plotino G, Hassanien EES. Instrumentation kinematics does not affect bacterial reduction, post-operative pain, and flare-ups: A randomized clinical trial. Int Endod J [Internet]. 2022 May 1 [cited 2024 Oct 20];55(5):405–15. Available from: https://pubmed.ncbi.nlm.nih.gov/35100456/
7. Sinsareekul C, Hiran-us S. Comparison of the efficacy of three different supplementary cleaning protocols in root-filled teeth with a bioceramic sealer after retreatment—a micro-computed tomographic study. Clinical Oral Investigations. 2022 Apr 1;26(4):3515–21.
8. Machado AG, Guilherme BPS, Provenzano JC, Marceliano-Alves MF, Gonçalves LS, Siqueira JF, et al. Effects of preparation with the Self-Adjusting File, TRUShape and XP-endo Shaper systems, and a supplementary step with XP-endo Finisher R on filling material removal during retreatment of mandibular molar canals. Int Endodontic Journal [Internet]. 2019 May 1 [cited 2024 May 26];52(5):709–15. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/iej.13039
9. XP-endo Rise | FKG Dentaire [Internet]. [cited 2024 May 26]. Available from: https://www.fkg.ch/products/endodontics/canal-shaping-and-cleaning/xp-endo-rise
10. Lim M, Jung C, Shin DH, Cho Y bum, Song M. Calcium silicate-based root canal sealers: a literature review. Restor Dent Endod. 2020;45(3).
11. Rekha R, Kavitha R, Venkitachalam R, Prabath SV, Deepthy S, Krishnan V. Comparison of the sealing ability of bioceramic sealer against epoxy resin-based sealer: A systematic review & meta-analysis. J Oral Biol Craniofac Res [Internet]. 2023 Jan 1 [cited 2024 Jul 7];13(1):28. Available from: /pmc/articles/PMC9636474/
12. Nawar N, Elashiry M, El-Baana, Saber S, Schäfer E. Ex-vivo evaluation of clinically-set hydraulic sealers used with different canal dryness protocols and obturation techniques: a randomized clinical trial. Clinical Oral Investigations, 2024, 28:612. https://doi.org/10.1007/s00784-024-06006-5
13. Hamdy TM, Galal MM, Ismail AG, Saber S. Physicochemical properties of AH plus bioceramic sealer, Bio-C Sealer, and ADseal root canal sealer. Head Face Medicine. 2024;20:1–9.
14. Saber S, Galal MM, Ismail AG, Hamdy TM. Thermal, chemical and physical analysis of VDW.1Seal, Fill Root ST, and ADseal root canal sealers. Scientific Reports. 2023;13:1–9.
15. Saber SM, Gomaa SM, Elashiry MM, El-Banna A, Schäfer E. Comparative biological properties of resin-free and resin-based calcium silicate-based endodontic repair materials on human periodontal ligament stem cells. Clinical Oral Investigations [Internet]. 2023 Nov 1 [cited 2024 Oct 20];27(11):6757–68. Available from: https://link.springer.com/article/10.1007/s00784-023-05288-5
16. Dong X, Xu X. Bioceramics in Endodontics: Updates and Future Perspectives. Bioengineering [Internet]. 2023 Mar 1 [cited 2024 Sep 17];10(3). Available from: /pmc/articles/PMC10045528/
17. Guivarch M, Jeanneau C, Giraud T, Pommel L, About I, Azim AA, et al. An international survey on the use of calcium silicate-based sealers in non-surgical endodontic treatment. Clinic Oral Investigation [Internet]. 2020 Jan 1 [cited 2024 Jun 24];24(1):417–24. Available from: https://link.springer.com/article/10.1007/s00784-019-02920-1
18. de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, Chu R, Cunha RS. Evaluation of the Efficacy of TRUShape and Reciproc File Systems in the Removal of Root Filling Material: An Ex Vivo Micro-Computed Tomographic Study. J Endod. 2016 Feb 1;42(2):315–9.
19. 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. Clinical Oral Investigation. 2021 Jun 1;25(6):4163–73.
20. Azim AA, Wang HH, Tarrosh M, Azim KA, Piasecki L. Comparison between Single-file Rotary Systems: Part 1—Efficiency, Effectiveness, and Adverse Effects in Endodontic Retreatment. J Endod. 2018 Nov 1;44(11):1720–4.
21. Pawar A, Thakur B, Metzger Z, Kfir A, Pawar M. The efficacy of the Self-Adjusting File versus WaveOne in removal of root filling residue that remains in oval canals after the use of ProTaper retreatment files: A cone-beam computed tomography study. J Conserv Dent [Internet]. 2016 Jan 1 [cited 2024 Oct 27];19(1):72. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC4760020/
22. Universität Düsseldorf: G*Power [Internet]. [cited 2024 Sep 8]. Available from: https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower
23. Drukteinis S. Hydraulic calcium silicate-based materials for root canal obturation. Clinical Dentistry Reviewed. 2022 Jan 27;6(1).
24. Shenoi PR, Badole GP, Khode RT. Evaluation of softening ability of Xylene & Endosolv-R on three different epoxy resin based sealers within 1 to 2 minutes - an in vitro study. Restor Dent Endod. 2014;39(1):17.

25. Marchi V, Scheire J, Simon S. Retreatment of Root Canals Filled with BioRoot RCS: An In Vitro Experimental Study. J Endod. 2020 Jun 1;46(6):858–62.
26. Volponi A, Pelegrine RA, Kato AS, Stringheta CP, Lopes RT, Silva AS de S, et al. Micro–computed Tomographic Assessment of Supplementary Cleaning Techniques for Removing Bioceramic Sealer and Gutta-percha in Oval Canals. J Endod. 2020 Dec 1;46(12):1901–6.
27. Shetty H, Shetty S, Kakade A, Shetty A, Karobari MI, Pawar AM, et al. Three-dimensional semi-automated volumetric assessment of the pulp space of teeth following regenerative dental procedures. Sci Rep. 2021 Dec 1;11(1).
28. jamovi - open statistical software for the desktop and cloud [Internet]. [cited 2024 Sep 3]. Available from: https://www.jamovi.org/
29. Shalabi M, Saber S, Elsewify T. Influence of blood contamination on the bond strength and biointeractivity of Biodentine used as root-end filling. Saudi Dent J. 2020 Dec 1;32(8):373–81.
30. 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. Clinical Oral Investigations. 2018 Mar 1;22(2):811–7.
31. Zuolo ML, De-Deus G, Belladonna FG, Silva EJNL da, Lopes RT, Souza EM, et al. Micro–computed Tomography Assessment of Dentinal Micro-cracks after Root Canal Preparation with TRUShape and Self-adjusting File Systems. J Endod [Internet]. 2017 Apr 1 [cited 2024 Jun 2];43(4):619–22. Available from: http://www.jendodon.com/article/S0099239916309426/fulltext
32. Oltra E, Cox TC, LaCourse MR, Johnson JD, Paranjpe A. Retreatability of two endodontic sealers, EndoSequence BC Sealer and AH Plus: a micro-computed tomographic comparison. Restor Dent Endod [Internet]. 2017 Feb 1 [cited 2024 Jun 2];42(1):19–26. Available from: https://doi.org/10.5395/rde.2017.42.1.19
33. Kim H, Kim E, Lee SJ, Shin SJ. Comparisons of the Retreatment Efficacy of Calcium Silicate and Epoxy Resin-based Sealers and Residual Sealer in Dentinal Tubules. J Endod [Internet]. 2015 Dec 1 [cited 2024 Jun 3];41(12):2025–30. Available from: http://www.jendodon.com/article/S0099239915007955/fulltext
34. Burroughs JR, Bergeron BE, Roberts MD, Hagan JL, Himel VT. Shaping ability of three nickel-titanium endodontic file systems in simulated s-shaped root canals. J Endod [Internet]. 2012 Dec 1 [cited 2024 Jun 18];38(12):1618–21. Available from: http://www.jendodon.com/article/S0099239912008771/fulltext
35. Yavuz Y, Akleyin E, Doğan MS, Goncharuk-Khomyn M, Akkus Z. Can the Density of Mineralized Dental Tissues (Dentin and Enamel) Be Measured and Compared with 3D Cone Beam Computed Tomography in Cases of Ectodermal Dysplasia? Med Sci Monit [Internet]. 2022 Jul 1 [cited 2024 Sep 24];28. Available from: https://pubmed.ncbi.nlm.nih.gov/35773958/
36. 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 Nov;38(11):1516–20.
37. Uzunoglu E, Yilmaz Z, Deniz Sungur D, Altundasar E. Retreatability of Root Canals Obturated Using Gutta-Percha with Bioceramic, MTA and Resin-Based Sealers. Vol. 10, IEJ Iranian Endodontic Journal. 2015.
38. Carpenter MT, Sidow SJ, Lindsey KW, Chuang A, McPherson JC. Regaining apical patency after obturation with gutta-percha and a sealer containing mineral trioxide aggregate. J Endod [Internet]. 2014 Apr 1 [cited 2024 Jul 1];40(4):588–90. Available from: http://www.jendodon.com/article/S0099239913009461/fulltext
39. Alemam S, Abuelsadat S, Saber S, Elsewify T. Accuracy, sensitivity and specificity of three imaging modalities in detection of separated intracanal instruments. Italian Endodontic Journal 2020 (34)1:97-103. Doi; 10.32067/GIE.2020.34.01.03
40. Saber S, Ek Sadat S, Taha A, Nawar N, Azim A. Anatomical Analysis of Mandibular Posterior Teeth using CBCT: An Endo-Surgical Perspective. European Endodontic Journal. 2021, 6(3):264-270.
41. Kwak SW, Ha JH, Lee W, Kim SK, Kim HC. Buckling resistance, bending stiffness, and torsional resistance of various instruments for canal exploration and glide path preparation. Restor Dent Endod. 2014;39(4):270.
42. 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. Australian Endodontic Journal. 2019 Dec 1;45(3):337–45.
43. Agrafioti A, Koursoumis AD, Kontakiotis EG. Re-establishing apical patency after obturation with Gutta-percha and two novel calcium silicate-based sealers. Eur J Dent [Internet]. 2015 [cited 2024 May 25];9(4):457–61. Available from: http://www.thieme-connect.de/DOI/DOI?10.4103/1305-7456.172625

44. Romeiro K, de Almeida A, Cassimiro M, Gominho L, Dantas E, Chagas N, et al. Reciproc and Reciproc Blue in the removal of bioceramic and resin-based sealers in retreatment procedures. Clin Oral Investig. 2020 Jan 1;24(1):405–16.
45. Alsubait S, Alhathlool N, Alqedairi A, Alfawaz H. A micro-computed tomographic evaluation of retreatability of BioRoot RCS in comparison with AH Plus. Aust Endod J [Internet]. 2023 Aug 1 [cited 2024 Jun 29];49(2):459. Available from: https://pubmed.ncbi.nlm.nih.gov/35861399/
46. Liu H, Lai WWM, Hieawy A, Gao Y, Haapasalo M, Tay FR, et al. Efficacy of XP-endo instruments in removing 54 month-aged root canal filling material from mandibular molars. J Dent. 2021 Sep 1;112.
47. 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. Journal of Conservative Dentistry. 2019 Nov 1;22(6):578–82.
48. Sadat SMA El, Chew HP, Fok A, Elashiry MM, ElShenawy AM, Saber S. Quality of different obturation techniques to fill perforating internal root resorption: a micro-computed tomographic study. BMC Oral Health. 2024 Dec 1;24(1).