

Retreatability of Bioceramic Sealer Using One Curve Rotary File Assessed by Microcomputed Tomography

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ABSTRACT

Aim and objective: This article aims to evaluate the residual filling materials after retreatment of bioceramic sealer used in the obturation technique of mandibular molars with different root curvatures using microcomputed tomography (micro-CT).

Materials and methods: A total of 106 canals of mandibular molar teeth with closed apex, no fracture, calcification, or previously root canals treated were selected. Each tooth was mounted in acrylic resin blocks, and canals were instrumented with 06 One Curve rotary file and filled with gutta-percha and EndoSequence bioceramic (group A) or AH Plus sealer (group B) then subdivided into three groups (each) based on the degree of root curvature; mild ($\leq 15^\circ$), moderate ($16-30^\circ$), or severe ($\geq 31^\circ$). Retreatment was done with the same rotary file. Samples were scanned before and after retreatment, and the volume of the residual materials was calculated. Data were statistically analyzed.

Results: The micro-CT scans show remaining filling in all canal levels of the two groups after retreatment. The mean values of all canals in bioceramic as well as AH Plus samples were significantly higher at coronal level ($p < 0.001$). In addition, the mean differences of distolingual canal after retreatment were not significantly different between the three levels in bioceramic group ($p = 0.051$). In regard to the AH Plus group, the mean values of mesiolingual canal after retreatment were statistically significant higher at coronal level ($p < 0.001$).

Conclusion: Micro-CT tool provides a clear 3D visualization. Remnants of Bioceramic and AH Plus sealers were detected in different canal curvatures. The use of One Curve rotary file did not improve the removal of the filling materials.

Clinical significance: It is difficult to achieved complete removal of bioceramic filling material from the root canal system using rotary file.

Keywords: AH Plus sealer, Bioceramic sealer, Mandibular molar, Microcomputed tomography, Root canal retreatment.

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INTRODUCTION

Root canal retreatment is the treatment of choice in cases of failed primary root canal. This procedure is usually performed in cases with inadequate cleaning, shaping and obturation, iatrogenic events, or reinfection of the root canal system due to loss of the coronal seal after completion of root canal treatment.¹

Root canal-filled teeth have a high prevalence of radiographic signs of apical pathology,² with a rate of 40% reported for endodontically treated teeth in a cross-sectional study.³

Persistent apical pathosis and the development of new lesions are signs of treatment failure. The presence of microorganisms and their by-products in the root canal system were reported as the main reasons for treatment failure.⁴

Access to contaminated areas inside the root canal system is essential for successful retreatment. Therefore, complete removal of the previous root canal filling is necessary to gain access to the infected areas, such as dentinal tubules and isthmus.⁵

The sealer should not only create an excellent seal but must also be well tolerated by the periradicular tissues and be easy to manipulate so that optimum physical properties can be achieved although predictable clinical results have been obtained with the use of nonbonding root canal sealers.⁶

Traditional sealers have serious shortcomings, in that they generally shrink on setting and wash out in the presence of tissue fluids.⁷

Recently, calcium silicate-based sealers, such as EndoSequence BC (Brasseler, Savannah, Georgia, USA), have been introduced for obturation that can be successfully performed by practitioners, and benefits from biocompatibility and antibacterial during the

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setting reaction because of the highly alkaline pH and good physical properties.^{8,9} Calcium silicate-based sealers have low cytotoxicity and adequate suitable bonding strength and sealing ability.¹⁰ In addition, these sealers do not shrink upon setting, resulting in a gap-free interface between the gutta-percha, sealer, and dentine. However, although the clinical utility and biocompatibility of these materials showed promise in recent studies, the results have varied significantly.³ The interface between dentine and root canal filling material makes the removal of residual material challenging. Therefore, the amount of residual material left may interfere with the outcome of endodontic treatment. Using microcomputed tomography (micro-CT), this study evaluated residual filling material after retreatment with bioceramic sealer for obturation of mandibular molars with different root curvatures.

MATERIALS AND METHODS

Ethical Approval

Ethical approval was obtained from the Research Ethics Committee (institutional review board approval number: FPGRP/2020/504/294/283).

Specimen Selection and Initial Preparation

A total of 143 canals of permanent sound mandibular first and second molars were prescanned radiographically and with a micro-CT scanner (SkyScan 1172; Bruker MicroCT, Kontich, Belgium) before preparation to determine the overall outline of the canal anatomy. Based on the two- and three-dimensional models of the root canal obtained from these prescan images, 106 root canals [36 mesiobuccal (MB), 31 mesiolingual (ML), 36 distobuccal (DB), and 3 distolingual (DL)] were chosen for the experiment.

Sample selection was based on the following inclusion criteria: roots with closed apex, no internal or external resorption, no fracture, and no previous root canal treatment or calcification. Teeth with signs of previous endodontic treatment, root caries, fractures or cracks, or signs of resorption were excluded.

According to the sample size calculation, the samples were randomly divided into two groups; one treated with EndoSequence BC (Bioceramic Group, $n = 54$) and the other with AH Plus sealer (AH Plus Group, $n = 52$). Each group was further divided into three subgroups based on the degree of root curvature, determined according to the method of Schneider:¹¹ mild ($\leq 15^\circ$), moderate ($16^\circ\text{--}30^\circ$), or severe ($\geq 31^\circ$) (Flowchart 1).

Root Canal Procedure

Each tooth was individually mounted in prenumbered self-curing acrylic resin blocks 15 mm in width and 10 mm in height. An access cavity was made using a round size four diamond bur, and the working length was determined with a size 10 K-file (Dentsply Maillefer, Tulsa, Oklahoma, USA) by inserting the file into the canal until the tip appeared through the apical foramen and then subtracting 1 mm. Teeth were instrumented to the full working length with a rotary file (size 25, taper 06; One Curve; Micro-Mega, Besançon, France) coupled to an X-Smart Plus engine (X-Smart Plus Endo Motor; Dentsply Maillefer) at a speed of 300 rpm and torque of 2.5 Ncm, according to the manufacturer's suggested method and settings. Sodium hypochlorite (2.5%) with a 27-G needle (Ultradent Inc., South Jordan, Utah, USA) was used during canal preparation as an irrigant. Final irrigation of each canal was done with 5 mL of 17% EDTA for 1 minute followed by 5 mL of 2.5% sodium hypochlorite

and 5 mL of sterile saline. The canals were dried using paper points (Dentsply Maillefer). Roots were then scanned in a micro-CT scanner (SkyScan 1172; Bruker MicroCT). Canals were filled using the vertical condensation technique, as follows:

Bioceramic Group: EndoSequence BC Sealer

The prepared root canals were filled with premixed EndoSequence BC sealer (Brasseler) in ready-to-use syringes according to the manufacturer's recommendations. A single matched gutta-percha cone (size 25, taper 06; Meta-Biomed, Cheongju, Republic of Korea) coated with the sealer was then placed slowly in the canal with vertical compaction to fill the walls of the root canals. The filling materials were seared off at the orifice and lightly compacted with a size #1 Buchanan™ Hand Plugger (Kerr, Bioggio, Switzerland). Excess coronal filling was precut to the canal orifice level, and the access cavity was then closed with Cavit (ESPE-Premier, Norristown, Pennsylvania, USA).

AH Plus Group: AH Plus Sealer

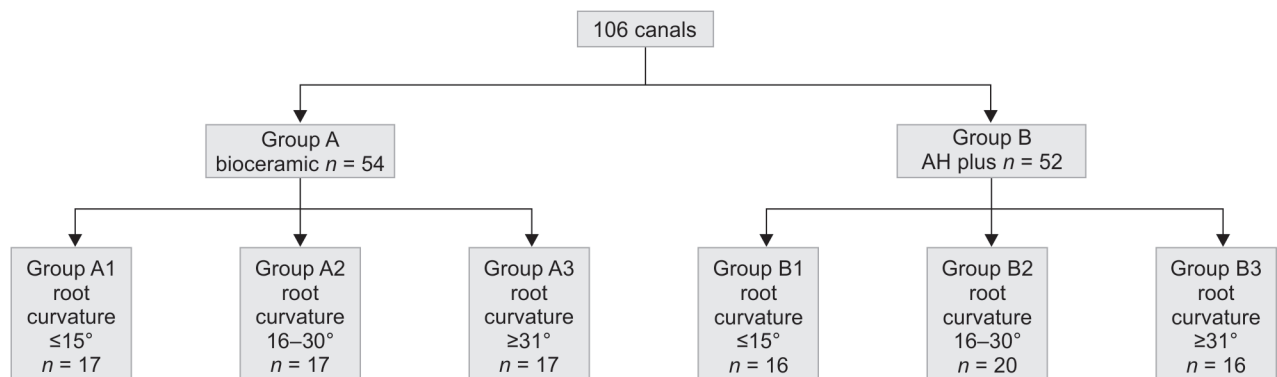
AH Plus sealer was mixed using the AH Plus Jet mixing system (De Trey Dentsply, Konstanz, Germany) and then placed into the prepared canals using Lentulo spiral (Dentsply Maillefer). The continuous wave condensation technique, with a gutta-percha-matching cone size of 25 (taper 06; Meta-Biomed), was used. The gutta-percha was placed in the canal along with the sealer, and the fine tip of the Buchanan™ Heat Plugger (Kerr) was used with a System B Heat Source set to 350°C. The activated tip was inserted into the gutta-percha cone in the canal within 3 mm short of the working length, with sustained apical pressure until resistance was felt. The tip was allowed to cool for 5 seconds and then removed, and the filling was gently condensed. A backfill procedure was performed using Obtura III Max (Obtura Spartan Endodontics, Algonquin, Illinois, USA) by plasticizing the gutta-percha at 200°C, followed by condensation using a size #1 Buchanan™ Hand Plugger (Kerr). Excess material was removed and the access cavity was closed with Cavit (ESPE-Premier).

All samples were scanned in a micro-CT scanner (SkyScan 1172; Bruker MicroCT) and then incubated at 37°C (100% humidity) for 2 weeks to allow the sealer to set completely.

Retreatment

Samples were retreated with the same rotary file (One Curve) coupled to the X-Smart Plus engine at a speed of 300 rpm and torque of 2.5 Nm without solvent. One file was used per canal. Retreatment was considered complete when the working length

Flowchart 1: Distribution of the experimental groups



was reached, and no materials were observed on the instruments. Canals were rinsed with 10 mL of 2.5% sodium hypochlorite and dried with paper points, and the access cavity was closed with a temporary filling (Cavit; ESPE-Premier).

To reduce variation in the final results, the prenumbered samples were assigned another number, and the retreatment procedure was performed in a blinded manner by the same operator who performed the root canal procedure. The operator was blinded to the sealer group and type of root curvature. The retreatment procedure was performed under magnification using Prismatic 4.0 × TTL Loupes with a headlight system (PeriOptix; Den-Mat Holdings, Lompoc, California, USA). Specimens were again scanned in the micro-CT scanner (SkyScan 1172; Bruker MicroCT).

Microcomputed Tomography Analysis

Samples were scanned after instrumentation (first scan), canal filling (second scan), and retreatment (third scan) using a micro-CT scanner (SkyScan 1172; Bruker MicroCT) that allows for scanning of high-density objects, with an isotropic voxel size of 11.88 μm and copper–aluminum filter. The scanning parameters were as follows: X-ray voltage of 100 kV (10 W and 100 μA), exposure time of 1,475 ms, and 360° rotation in 0.4° steps.

The images were reconstructed with NRecon v.1.6.9 SkyScan software (Bruker MicroCT) using the modified Feldkamp cone-beam reconstruction algorithm. The original greyscale images were processed for noise reduction with the fine-tuning function: Gaussian filter (smoothing, kernel = 2), beam hardening correction of 40%, postalignment of 0.50 to compensate for possible misalignment during acquisition, and ring artefact correction of 10. The resulting images produced by the three scans were geometrically aligned using the 3D registration function of the DataViewer v.1.5.1 software (Bruker MicroCT). The residual materials at the apical, middle, and coronal levels of the root were measured. The residual filling material was measured, and the image data sets were processed with CTAn v.1.14.4 software (Bruker MicroCT). The amounts of residual filling material were compared between groups.

Statistical Analysis

Descriptive statistics are presented as the mean and standard deviation. Comparisons of residual filling material among different curvatures and sealers were performed by one-way ANOVA. Data analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, New York, USA). In all analyses, $p < 0.05$ was taken to indicate statistical significance.

RESULTS

Working length determination revealed 19 MB canals joining the ML canals at the apical level of the root apex. Similar findings were observed in two of the distal canals (one DB and one DL).

Comparison between the Bioceramic Group and AH Plus Group at Different Levels

The normality of the data distribution was examined using a normality test. Continuous data following a normal distribution are presented as mean values. The mean values were compared between the groups.

Comparison of the mean canal diameter scanned at three different levels between the two sealer groups (Table 1) revealed a significantly higher at the coronal level ($p < 0.001$). This was also noted in all canals on the first, second, and third scans ($p < 0.001$).

Residual Filling Material in the Bioceramic Group and AH Plus Group

Micro-CT of the retreated canals showed residual filling material in most of the specimens in the Bioceramic Group at different levels, regardless of the root curvature angle (Fig. 1).

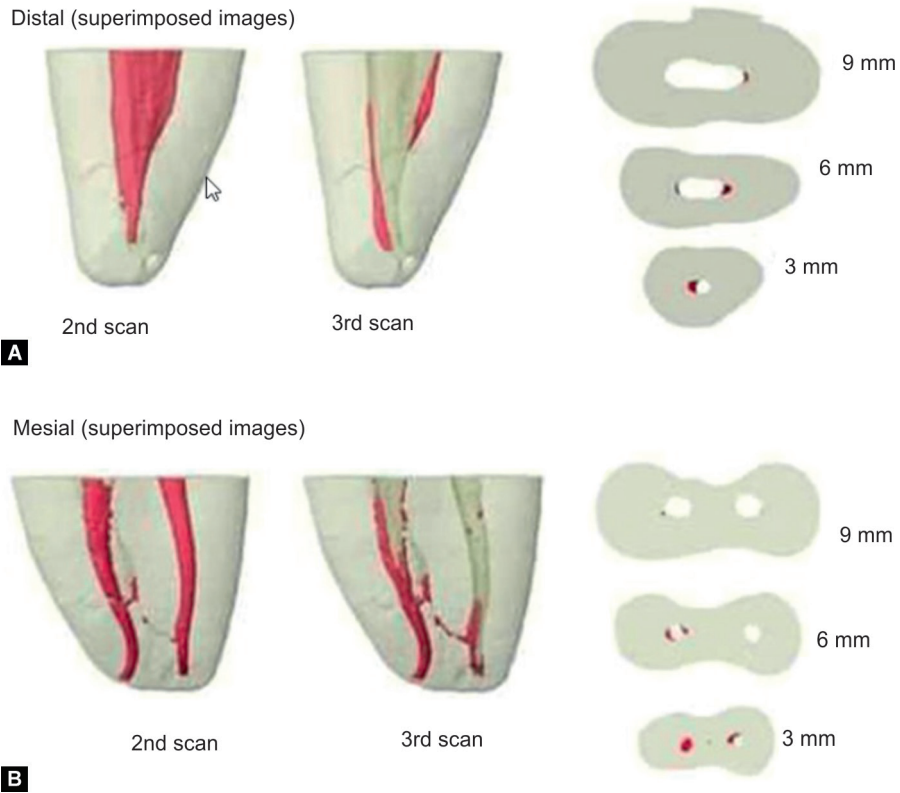
Residual filling material was seen in most of the specimens in the AH Plus Group at different levels, regardless of the root curvature angle (Fig. 2).

Table 2 and Figure 3 compare residual filling material for both sealers in the various canals. Lower levels of remnant material were found in the MB canal in the Bioceramic Group (0.45 ± 0.54)

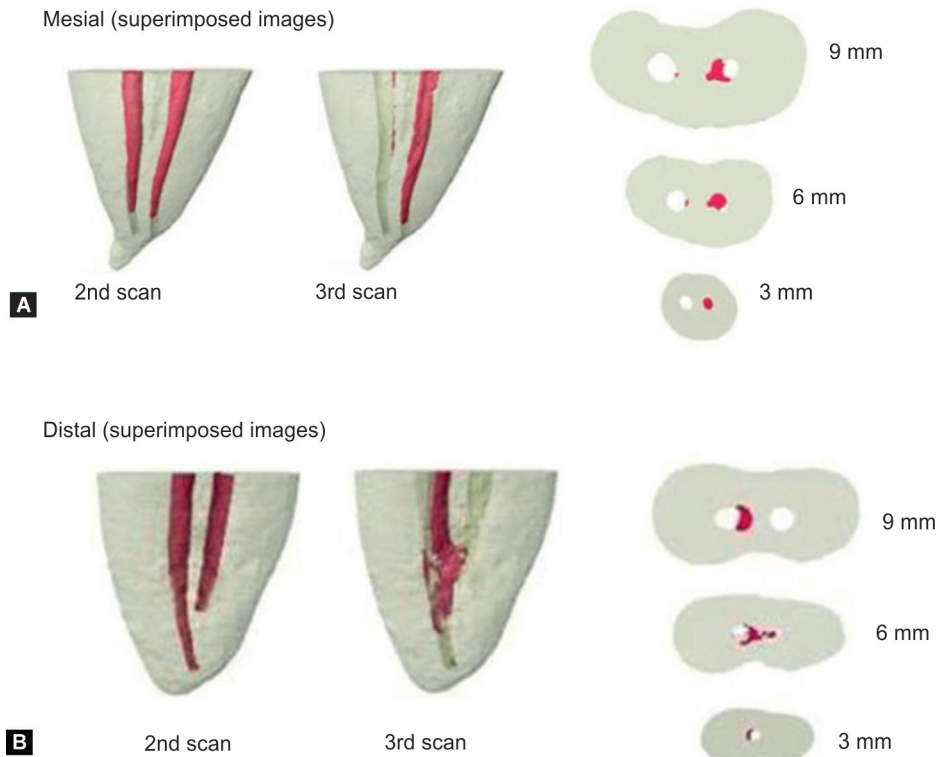
Table 1: Comparison between values of different canal levels between groups

Root canal	Apical Mean ± SD	Level of the canals		p [§]
		Middle Mean ± SD	Coronal Mean ± SD	
Mesiobuccal				
Postinstrumentation	0.39 ± 0.09	0.58 ± 0.10	0.82 ± 0.12	<0.001*
Postfilling	0.47 ± 0.08	0.66 ± 0.10	0.89 ± 0.10	<0.001*
Postretreatment	0.52 ± 0.09	0.68 ± 0.17	0.95 ± 0.12	<0.001*
Mesiolingual				
Postinstrumentation	0.41 ± 0.12	0.62 ± 0.10	0.83 ± 0.11	<0.001*
Postfilling	0.49 ± 0.09	0.70 ± 0.07	0.92 ± 0.07	<0.001*
Postretreatment	0.54 ± 0.10	0.76 ± 0.08	0.97 ± 0.07	<0.001*
Distobuccal				
Postinstrumentation	0.46 ± 0.09	0.68 ± 0.10	0.92 ± 0.15	<0.001*
Postfilling	0.49 ± 0.10	0.75 ± 0.11	0.97 ± 0.15	<0.001*
Postretreatment	0.58 ± 0.15	0.84 ± 0.12	1.07 ± 0.15	<0.001*
Distolingual				
Postinstrumentation	0.35 ± 0.03	0.59 ± 0.12	0.78 ± 0.04	0.001*
Postfilling	0.46 ± 0.02	0.72 ± 0.03	0.84 ± 0.03	<0.001*
Postretreatment	0.53 ± 0.06	0.78 ± 0.12	0.90 ± 0.06	0.004*

[§]p has been calculated using one-way ANOVA test; *Significant at $p < 0.001$ level; $P < 0.001$ means statistically highly significant



Figs 1A and B: Micro-CT photo of group A showing little remaining filling in the canal wall at all levels of the distal as well as the MB canal after retreatment (scan 3). The ML canal shows no remnants of root canal filling at the middle (6 mm) and coronal (9 mm) level



Figs 2A and B: (A) Micro-CT photo of the mesial canals of group B showing little remaining filling in the canal wall at 9 and 6 mm level and clean at 3 mm level of the ML canal after retreatment (scan 3). The MB canal shows remnants of root canal filling at the coronal, middle and apical level; (B) Micro-CT photo of the distal canals of group B showing remaining filling at different levels except the coronal (9 mm) level of the distolingual canal

Table 2: Comparison of residual filling materials between groups in different canals

Residual filling materials per canal (mm ³)	Type of sealer		§p
	AH Plus	BC	
	Mean ± SD	Mean ± SD	
MB	0.65 ± 0.56	0.45 ± 0.54	0.368
ML	0.71 ± 0.60	0.86 ± 0.84	0.614
DB	1.31 ± 0.96	1.19 ± 1.33	0.764
DL	0.21 ± 0.07	1.18 ± —	0.038*

§p has been calculated using one-way ANOVA test; *Significant at p < 0.038 level; p = 0.038 means that there is only a 3.8% chance that this observed difference between the groups occurred by chance (which is less than the traditional cutoff of 5%) and therefore, statistically significant

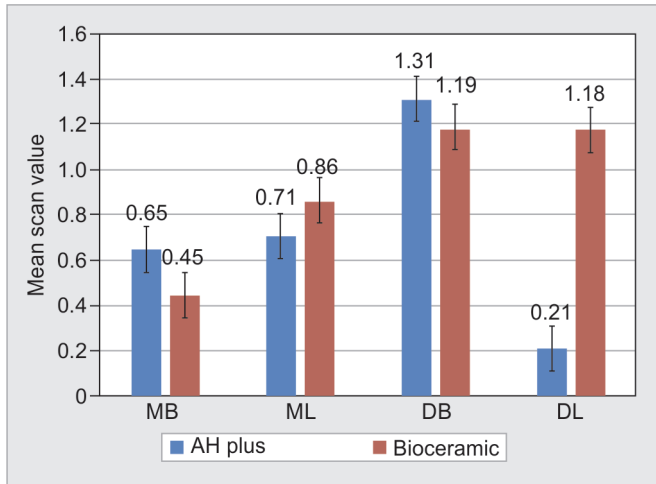


Fig. 3: Average comparison of residual filling materials in the root canals of both sealers

Table 3: Comparison of residual filling materials in relation to angle of root curvature in BC sealer subgroups

Residual Filling materials (mm ³)	Root curvature group			§p
	Subgroups A1	Subgroups A2	Subgroups A3	
MB	0.43 ± 0.19	0.32 ± 0.20	0.83 ± 1.18	0.403
ML	0.56 ± 0.46	0.81 ± 0.98	1.16 ± 0.89	0.666
DB	2.37 ± 1.41	0.41 ± 0.26	0.41 ± 0.47	0.007*
DL	0.15 ± —	0.26 ± —	—	—

§p has been calculated using one-way ANOVA test; *Significant at p < 0.007 level; P = 0.007 means a degree of "significance" to the result that belies its clinical interpretation

compared to the DL canal in the AH Plus Group (0.21 ± 0.07). The mean level of remnant material in the DL canal was significantly higher in the Bioceramic Group than the AH Plus Group (p = 0.038). On the other hand, although the mean values of the MB (p = 0.368) and DB (p = 0.764) canals were higher in the AH Plus Group than the Bioceramic Group, neither difference reached statistical significance. In addition, the difference in the mean value for the ML canal between the AH Plus Group and Bioceramic Group was not statistically significant (p = 0.614).

Table 3 and Figure 4 compare residual filling material among Bioceramic subgroups distinguished according to the degree of root curvature: mild (≤15°), moderate (16°–30°), or severe (≥31°). The mean value for the DB canal (2.37 ± 1.41) was significantly higher

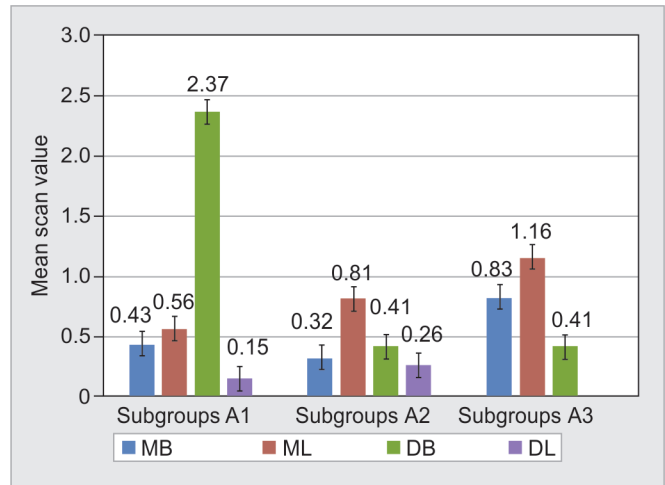


Fig. 4: Average comparison of residual filling materials in the root canals of different curvatures of BC sealer subgroups

Table 4: Comparison of residual filling materials in relation to angle of root curvature in AH plus sealer subgroups

Residual filling materials (mm ³)	Root curvature group			§p
	Subgroups B1	Subgroups B2	Subgroups B3	
MB	0.25 ± 11.9	0.57 ± 0.45	0.97 ± 0.76	0.339
ML	0.21 ± —	0.66 ± 0.44	0.92 ± 0.79	0.411
DB	1.44 ± 1.08	0.83 ± 0.72	1.85 ± 0.29	0.380*
DL	—	—	—	—

§p has been calculated using one-way ANOVA test; *Significant at p < 0.05 level

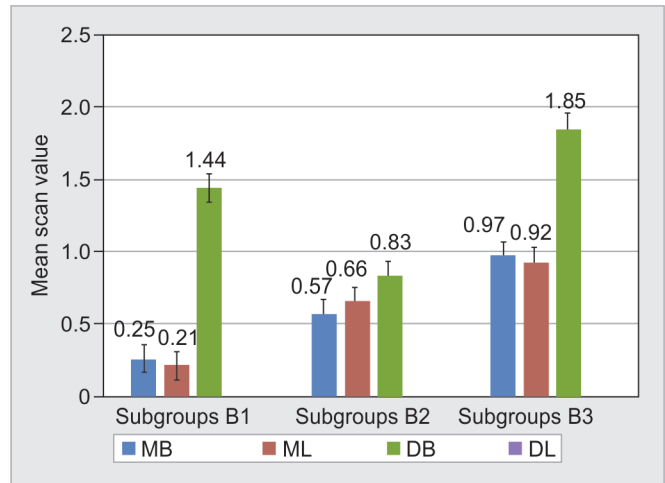


Fig. 5: Average comparison of residual filling materials in the root canals of different root curvatures of AH Plus sealer subgroups

in the Bioceramic mild curvature (≤15°) subgroup than the other two subgroups (p = 0.007). In contrast, the mean values for the MB, ML, and DL canals were not significantly different among the three curvature subgroups (all p > 0.05).

Table 4 and Figure 5 compare residual filling material among AH Plus subgroups distinguished according to root curvature. The

Table 5: Paired *t*-test of root canal scanned results performed in three different occasions for all groups

<i>Mesiobuccal</i>	<i>Scan count</i>	<i>Mean ± SD</i>	<i>Mean diff.</i>	<i>Std. error</i>	<i>95% CI</i>		<i>p</i> [§]
					<i>Lower</i>	<i>Upper</i>	
<i>Mesiobuccal</i>	Postinstrumentation	0.61 ± 0.19	-0.070	0.007	-0.083	-0.057	<0.001**
	Postfilling	0.68 ± 0.19					
	Postinstrumentation	0.61 ± 0.19	-0.112	0.012	-0.135	-0.089	<0.001**
	Postretreatment	0.72 ± 0.22					
	Postfilling	0.68 ± 0.19	-0.042	0.009	-0.061	0.023	<0.001**
	Postretreatment	0.72 ± 0.22					
<i>Mesiolingual</i>	Postinstrumentation	0.63 ± 0.20	-0.081	0.009	-0.099	-0.063	<0.001**
	Postfilling	0.71 ± 0.19					
	Postinstrumentation	0.63 ± 0.20	-0.136	0.011	-0.157	-0.114	<0.001**
	Postretreatment	0.77 ± 0.19					
	Postfilling	0.71 ± 0.19	-0.054	0.007	-0.068	-0.040	<0.001**
	Postretreatment	0.77 ± 0.19					
<i>Distobuccal</i>	Postinstrumentation	0.69 ± 0.22	-0.055	0.006	-0.067	-0.043	<0.001**
	Postfilling	0.74 ± 0.23					
	Postinstrumentation	0.69 ± 0.22	-0.144	0.009	-0.164	-0.125	<0.001**
	Postretreatment	0.83 ± 0.24					
	Postfilling	0.74 ± 0.23	-0.089	0.009	-0.107	-0.070	<0.001**
	Postretreatment	0.83 ± 0.24					
<i>Distolingual</i>	Postinstrumentation	0.58 ± 0.19	-0.096	0.023	-0.150	0.041	0.003**
	Postfilling	0.67 ± 0.17					
	Postinstrumentation	0.58 ± 0.19	-0.157	0.025	-0.216	-0.101	<0.001**
	Postretreatment	0.74 ± 0.18					
	Postfilling	0.67 ± 0.17	-0.063	0.203	-0.109	-0.016	0.015*
	Postretreatment	0.74 ± 0.18					

[§]*p* has been calculated using one-way ANOVA test; **Significant at *p* < 0.05 level; *p* < 0.001 means statistically highly significant; *Significant at *p* < 0.05 level

results showed that the mean values for the MB, ML, and DB canals were higher in the AH Plus severe curvature ($\geq 31^\circ$) subgroup than the other subgroups, but these differences did not reach statistical significance (all *p* > 0.05).

Values for Different Scans and Groups

Table 5 compares the root canal scan results at three different time points between the groups. For the MB canal, the mean value of the second scan was significantly higher than that of the first (mean diff: -0.070; *p* < 0.001), whereas the mean value of the third scan was significantly higher than those of both the first (mean diff: -0.112; *p* < 0.001) and second scans (mean diff: -0.042; *p* < 0.001). For the ML canal, the mean value of the second scan was significantly higher than that of the first (mean diff: -0.081; *p* < 0.001), whereas the mean value of the third scan was significantly higher than those of the first (mean diff: -0.136; *p* < 0.001) and second scans (mean diff: -0.054; *p* < 0.001). For the DB canal, the mean value of the second scan was significantly higher than that of the first scan (mean diff: -0.055; *p* < 0.001), while the mean value of the third scan was significantly higher than those of both the first (mean diff: -0.144; *p* < 0.001) and second scans (mean diff: -0.089; *p* < 0.001). Finally, for the DL canal, the mean value of the second scan was significantly higher

than that of the first scan (mean diff: -0.096; *p* = 0.003), while the mean value of the third scan was significantly higher than those of both the first (mean diff: -0.157; *p* < 0.001) and second scans (mean diff: -0.063; *p* = 0.015).

DISCUSSION

Complete removal of the root canal filling is a challenge for all current retreatment techniques. No instruments or techniques are available that can completely remove root canal filling material from the root canal system during retreatment.¹²⁻¹⁶ This may decrease the effectiveness of disinfection procedures, irrigating solutions, and interappointment medication procedures,^{17,18} thus impairing the removal of microorganisms because chemical disinfection is more thorough in areas where the irrigant can come into direct contact with persisting microorganisms.¹⁹

In the present study, canal preparation was carried out using one NiTi rotary file system (size 25, taper 06; One Curve; Micro-Mega) to standardize the anatomical apical size. Significantly less canal transportation was seen than reported for the One Shape and ProTaper Next system for the apical zone.²⁰ The One Curve NiTi rotary file is a C-wire heat-treated alloy that offers a controlled

memory feature and the ability to prebend, for easier access to the root canal and elimination of constraints. It has an ideal taper and diameter for final shaping and its variable cross-section gives the instrument an excellent capacity for upward debris removal and good cutting efficiency. The triple helix cross-section of the first 4 mm at the tip increases the centering ability of the file in the root canal, while the S-shaped section in the medium and coronal parts promotes cutting efficiency and debris removal.²¹

Bioceramic sealer (EndoSequence BC; Brasseler) was used in this study because this type of sealer has been reported to induce the formation of hydroxyapatite tags, thereby contributing to its sealing abilities and ultimately rendering it more difficult to remove.²² This bond could be advantageous for sealability of the obturated canals but could also make removal very difficult if retreatment is necessary. It was compared to AH Plus sealer, which has been used extensively in previous research and is considered the standard against which to compare and evaluate the retreatability of endodontic sealers.^{8,23-25}

In the present study, retreatment was performed using an NiTi rotary file system of the same size as that used to prepare the root canals (size 25, taper 06; One Curve). The use of NiTi rotary files significantly affected the removal of filling material, similar to previous reports.^{14,26,27} Both bioceramic and AH Plus sealers were readily retreated using conventional methods with the ProTaper retreatment instruments.^{24,28} Rödiger et al.²⁹ also reported that ProTaper Universal Retreatment and Hedstrom files were equally effective in removing most of the filling materials in curved canals. This was contrary to Unal et al.³⁰ who reported that ProTaper Universal Retreatment files were less effective than hand instruments in curved canals. This was attributed to the use of a smaller-sized ProTaper Universal Retreatment file to remove the filling materials compared to that used to prepare the canal. Simsek et al.³¹ evaluated the effectiveness of retreatment with ultrasonic tips or R-Endo files for removal of filling materials from root canals by scanning electron microscopy. They reported that none of the retreatment techniques was able to remove debris present in the coronal, middle, or apical thirds of the roots completely, regardless of the sealer type.

No solvent was used in the present study to eliminate possible confounding effects³² although they are commonly used during endodontic retreatment.¹³ Solvent use led to greater amounts of residual material within the dentinal tubules due to increased solubility of the sealer.^{33,34} In addition, the softened gutta-percha can be pushed into irregularly shaped parts of the canal, making it more difficult to remove.³⁵ In retreatment cases, Hess et al.²³ reported that removal of bioceramic sealer using solvent and a rotary instrument, and reaching the correct working length, was not easy and patency was gained in only 20% of their experimental samples. The use of rotary instrumentation without solvent during retreatment plasticizes the gutta-percha through frictional heating, making it softer, less resistant, and easier to penetrate and remove.³⁶

A number of different methods, including scanning electron microscopy, radiographic examination, splitting, and clearing of the examined teeth, have been used to assess the removal of residual filling material from root canals after endodontic retreatment.^{30,31,37-39} A major drawback of these techniques for evaluating the effectiveness of retreatment is the inability to observe the canal during the various stages of canal instrumentation and after retreatment. The results of studies conducting two-dimensional assessments of only selected sections of the canal should be interpreted with caution because they may vary among observers, and loss of residual filling material may occur during the splitting of specimens.^{33,40}

More recently, micro-CT scanning has emerged as a preferred method, providing high-resolution 3D volumetric data suitable for analysis, quantification, and visualization of results.^{41,42} This nondestructive technique with high-resolution imaging was used successfully in the present study to determine the amount of residual filling material present in the root canal, similar to previous studies.^{13,25,26,29,32,43} Nano-CT (nano-CT), which produces ultra-precise radiographs via a high-power nanofocus X-ray source with a focal spot of only a few microns, was used to investigate voids and gaps in different root canal sealers and to explore the feasibility of its use for quantitative analysis of sealer filling quality. The disparate results indicated that the higher-resolution nano-CT modality is more able to distinguish internal porosity, suggesting the potential utility of nano-CT for quantitative analysis of the filling quality of sealers.⁴⁴

Root canals of the mesial and distal roots differing in curvature were evaluated at three levels in the present study (i.e., apical, middle, and coronal), similar to previous studies.^{13,42} These three levels were selected due to the high degree of anatomical variation in the apical third of the root canal. Most previous studies used a curvature angle <20° or a straight single root.^{13,16,23,26,28,45} In the present study, the canal curvature ranged from 0° to >30°. This was chosen to challenge the apical third of the studied samples.

Residual bioceramic and AH Plus filling material were detected in all subgroups, which were distinguished according to the degree of root curvature. The results showed that the mean values of residual bioceramic and AH Plus material in the MB, ML, and DB canals were not significantly different across the three root curvature groups (all $p > 0.05$). This may have been related to the use of a single instrumentation technique with the same rotary file system in this study.

Smaller amounts of residual material were found in the MB (0.45 ± 0.54) and DL canals (0.21 ± 0.07) in the AH Plus Group, as reported previously by Crozeta et al.¹⁶ This may have been related to the lower bond strength of bioceramic sealers.^{26,46} In addition, the mean amount of residual material in the DB canal (2.37 ± 1.41) was significantly greater in the mild root curvature Bioceramic Group subgroup.

In the AH Plus Group, the mean amounts of residual material in the MB, ML, and DB canals were larger in the severe root curvature subgroups. The AH Plus sealer interacts chemically with root dentine collagen networks treated with EDTA solution, through covalent bonds between the epoxy rings and amine groups exposed in the network.^{47,48} This type of adhesion results in monoblock obturation.⁴⁹

The mean amounts of residual material in all canals in the Bioceramic and AH Plus Groups were significantly greater at the coronal level ($p < 0.001$), similar to the findings of Uzunoglu et al.⁴² This may have been related to plasticization of the gutta-percha due to continuous rotation of the rotary file during retreatment in areas with high concentrations of filling material.⁵⁰

In contrast to the present study, previous studies demonstrated greater amounts of residual filling material in the apical third of the canal than the middle and coronal thirds, regardless of the sealer used.^{28,31,51} This may be related to the greater anatomical variation in the apical third in relation to the angle of root curvature and to differences in the tip sizes and tapers of instruments used for canal preparation and retreatment between studies. Several variables may have contributed to the discrepancy between the residual volumes in previously published studies, and no systems have been reported that are able to completely remove the material from a curved root canal. One factor to consider regarding the variation

in material reduction percentages among studies is the different obturation techniques used. Nevares et al.⁵² used a thermoplastic technique, while Rödiger et al.^{29,43} used a lateral condensation technique. Fruchi et al.⁵³ filled the canals using a single-cone technique, as in the present study, but they used solvent to facilitate removal of the gutta-percha.

Supplementary protocols have been proposed for use after the initial removal of filling material by mechanized systems. Volponi et al.⁴⁵ conducted micro-CT assessment of the effectiveness of three supplementary cleaning techniques (ultrasonic-assisted irrigation, EndoActivator irrigation and the XP-endo Finisher R system) for reducing residual volumes from the gutta-percha, and a bioceramic sealer, after performing endodontic retreatment procedures in teeth with oval canals. They concluded that none of the tested supplementary cleaning techniques completely removed the residual filling material, similar to the findings reported by Crozeta et al.¹⁶

In general, the amounts of filling material reportedly removed from the root canal depend on the calculation method and tool used. Similar to the present study, none of the previously published studies achieved complete removal of filling material from the root canal system.

Some limitations of this technique were related to methodological issues. Micro-CT cannot distinguish the gutta-percha from sealer remnants or evaluate the thickness and depth of sealer penetration into dentinal tubules.^{23,42} In addition, prescanned samples were not measured.

The following recommendations are made for further studies; the percentages of remaining filling material and dentine removed should be calculated for more accurate statistical analysis. More sophisticated tools, such as nano-CT, should be used for more detailed investigation.

CONCLUSION

The micro-CT analysis showed no differences in the amounts of residual filling material in the root canal between retreatment with bioceramic sealer and AH Plus sealer, regardless of the canal curvature or level. Furthermore, the use of a rotary file did not improve removal of the filling material. Although ideal canal cleanliness could not be achieved, reestablishment of the working length and patency were considered satisfactory.

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