

Effect of Obturation Technique on Retrievability of AH+ Bioceramic Sealer Evaluated with Different Methods: An In Vitro Study

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Abstract

Background: During non-surgical endodontic retreatment, it is necessary to remove all previous obturation materials. Using calcium silicate-based sealers, including AH Plus Bioceramic Sealer, may cause difficulties during re-treatment owing to their bonding and their penetration into the dentinal structure. The filling technique may affect the amount of remaining obturation material after re-treatment.

Aim: This in-vitro study aimed to assess the retrievability of AH Plus Bioceramic Sealer using two obturation techniques: single cone and cold lateral compaction.

Materials and Methods: Forty single-rooted human mandibular premolar teeth were used. Samples were randomly assigned to two groups (20 samples each) depending on the obturation technique: single cone or cold lateral compaction. Samples were filled with gutta-percha and AH Plus Bioceramic sealer then placed in an incubator at 37°C and 100% relative humidity for 3 weeks. Re-treatment was accomplished using rotary re-treatment and shaping files. The percentage of remaining obturation material was measured using cone beam computed tomography (CBCT), dental operating microscope (DOM), and digital periapical radiographs (PAs) from both proximal and frontal views. Time needed to reach working length and achieve patency was recorded.

Results: No statistically significant differences were found between the single cone and cold lateral compaction groups for the remaining obturation material as measured by CBCT, DOM, and proximal and frontal radiographic views. The P-values were 0.892, 0.808, 0.957, and 0.829. However, regarding the time to achieve patency, the single cone group had a statistically significantly longer time to achieve patency than the cold lateral compaction group, with an average time of 130.1 ± 29.9 seconds for the single cone group and 101.7 ± 24.8 seconds for the cold lateral compaction group ($P = 0.002$). no statistically significant difference between percentage of ROM measured by CBCT, DOM and Proximal view of PA; all showed statistically significant lower percentage of ROM compared to frontal view of PA. (P -value < 0.001 , Effect size = 0.533). the frontal view of digital PA and DOM showed statistically significant higher percentage of ROM than CBCT and proximal view of digital PA. There was no statistically significant difference between the frontal PA and DOM nor between CBCT and proximal PA. (P -value < 0.001 , Effect size = 0.483). As regards agreement between the four methods, there was substantial agreement between methods with Cronbach's alpha = 0.991 and Intra-Class Correlation Coefficient (ICC) = 0.965.

Conclusion: Using the three assessment methods, there was no significant difference in the remaining amount of obturation material after retreatment for the different obturation techniques. However, cold lateral compaction was significantly faster than the single-cone technique in achieving patency. CBCT, digital radiography, and microscopic assessment were useful for evaluating remaining obturation material,

Keywords: Calcium silicate-based sealer; CBCT; Cold lateral compaction; Endodontic retreatment; Single cone technique.

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Introduction

The favorable outcome provided by nonsurgical endodontic retreatment established this approach as the first line of treatment option when primary endodontic treatment fails⁽¹⁾. Failure of primary endodontic treatment was attributed to microbial infection whether it is persistent or emergent thus a thorough cleaning and proper disinfection is paramount to achieve the retreatment objective thus improving prognosis of secondary RCT⁽²⁾. During retreatment, all previous obturation materials should be removed as remaining obturation (ROM) may serve as reservoirs

for bacteria and act as physical barrier limiting the action of irrigation and medication increasing likelihood of persistent infection⁽³⁾.

Many variables have been found to affect removal of obturation material such as root anatomy, obturation quality and type of obturation material⁽⁴⁾. The introduction of calcium silicate-based sealer (CSBS) with its unique biological and bioactive properties lead to increase its popularity among clinician⁽⁵⁾. However, new issues related to its retrievability have emerged, with reports in the

literature indicating that its removal is difficult due to its chemical bonding with dentin and resistance to conventional solvents⁽⁶⁾. AH+ Bioceramic sealer (Dentsply Sirona, Charlotte, NC, USA) is premixed tricalcium silicate-based sealer that exhibits favorable physicochemical properties such as bioactivity and biocompatibility⁽⁷⁾ and limited research performed using this type of calcium silicate-based sealer. Additionally, obturation techniques have been reported to affect the sealer distribution, layer thickness and amount of sealer⁽⁸⁾, dentinal tubules penetration⁽⁹⁾ and remaining obturation material⁽¹⁰⁾. Single cone technique with calcium silicate-based sealer is a popular technique among general practitioner and has been associated the greater amount of sealer that might affect the remaining obturation material⁽¹¹⁾. Therefore, the method of obturation may influence the remaining obturation material that should be taken into account when evaluating the overall retrievability of CSBS sealers.

Various methods have been used to evaluate remaining obturation material and these include noninvasive imaging techniques such as 2D radiograph, CBCT and Micro-CT or invasive sectioning method. After sectioning procedure, examination performed using dental operating microscope, a stereomicroscope, a scanning electron microscope, or a combination of these⁽¹²⁾.

To our knowledge, few studies have compared single cone technique versus cold lateral compaction technique using AH+ Bioceramic sealer. This study aimed to evaluate the remaining obturation material using AH+ Bioceramic with single cone and cold lateral compaction techniques employing different evaluation methods. Also, this study aims to compare between these methods. These methods include digital radiographs frontal and proximal view, CBCT, and direct visualization using dental operating microscope (DOM). The first null hypothesis state that there is no difference between single cone (SC) and cold lateral compaction (CLC) techniques with regard to the remaining obturation materials (ROM). The second null hypothesis state that there is no difference between single cone and cold lateral compaction techniques with regard to time required to reach WL and achieve patency. The third null hypothesis state that there is no difference between digital periapical radiograph, CBCT and DOM.

Methodology

Study design

This in-vitro study was conducted at Endodontic Department, Faculty of Dental Medicine, Al-Azhar University. Ethical Approval was obtained from the Dentistry Faculty of Al-Azhar University's Ethics Committee (Ethical Code: 948/1876). This study was conducted in accordance with the Declaration of Helsinki and the PRILE Guidelines 2021⁽¹³⁾

Sample size calculation

sample size was calculated based on a study done by Azim et al.⁽¹⁴⁾ Using the G*Power (version 3.1.1 statistical software, Franz Faul, Universität Kiel Germany) statistical program with an α error probability of 0.05 and a power of 0.95. The findings indicated a minimum sample size was $n = 36$. The sample size was set to 40 to ensure convenience.

Sample population

A total of 40 human single-rooted mandibular premolars (age 20-30) extracted for orthodontic or periodontal reasons were obtained after obtaining patient's approval. The teeth were cleaned from debris using ultrasonic and disinfected with 5.25% NaOCl for 5 minutes. The teeth were then examined using a Dental Operating Microscope (DOM) at 20X magnification to exclude teeth with cracks, caries, and/or root resorption. Digital periapical radiograph in the mesiodistal and buccolingual directions were taken using the radiographic device shown in Figure (1). Then the teeth were selected according to the following inclusion and exclusion criteria:

Inclusion criteria:

- Single canal type 1 (Vertucci classification).
- Root with mature apices.
- Canal curvature (0° - 10°) following Schneider methods⁽¹⁵⁾.
- Tooth length 21 ± 1 mm.

Exclusion criteria:

- Root caries and/or resorption.
- Root canal calcification or obliteration.
- Canal bi/trifurcation.
- Canal with apical diameter greater than #15 ISO

Standardization of Periapical Radiographs

All the periapical radiographs in this study were performed using a Nanopix size 1 digital sensor (Eighteenth, Changzhou, Jiangsu Province, China), a Hyperlight portable X-ray machine (Eighteenth, Changzhou, Jiangsu Province, China), and a custom-made radiographic device. The custom-made radiographic device was fabricated to hold the sensor, sample and x-ray tube at a fixed distance and keep them in identical orientation during every projection thus avoiding any distortion or discrepancies.

Custom polyvinyl siloxane molds for each sample was made to ensure accurate repositioning of each sample during the radiographic procedures. Each mold incorporated a buccal and a reference line mark to ensure standard placement of each sample. The radiography exposure settings for each radiograph were 70 kVp, 2 mA, and 0.2 seconds.

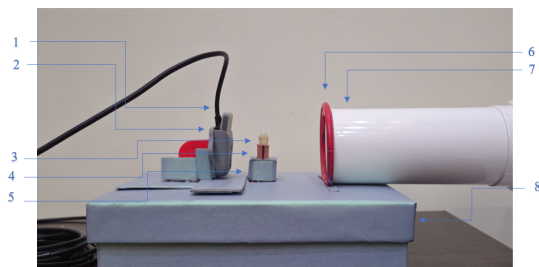


Figure 1 shows the radiographic device components 1. Digital sensor 2. Sensor holder 3. sample 4. sample mold 5. mold holder 6. x-ray machine tube 7. tube's positioning ring 8. the base

Sample Preparation

The samples were decoronated using a diamond disc under copious water to achieve a standardized root length of 16 mm and a stable reference point. The root canal system was irrigated with 2 mL of 5.25% sodium hypochlorite delivered via a #30G side-vented needle. Canal patency was achieved by the insertion of a #10 K-file so its tip was clearly visible at the apical foramen. Canals with an apical diameter greater than ISO size #15 were excluded and replaced. Until required for the study, the samples were stored in 0.9% saline.

Root Canal Preparation

The working length was determined by inserting a #10 K-file into the canal until its tip was clearly visible at the apical foramen under 5× magnification and the length was set as 0.5 mm shorter. A glide path was established by the insertion of #10 and #15 K-files to the full working length. Root canal preparation was performed using AF Blue rotary files (Fanta, Jiading District, Shanghai, China) with E-connect S rotary device (Eighteenth, Changzhou, Jiangsu Province, China) in the following sequence: #20.04; #25.04; #30.04, and #35.04. Files were used in continuous rotation mode and picking motion to the full working length. Torque and speed settings were set according to the manufacturer instructions (2.5 N/cm²-350 RPM) and each instrument was used for only one sample. Irrigation with 3 mL of 5.25% sodium hypochlorite was performed between each file using a #30G side-vented needle. Patency was maintained via recapitulation with a #10 K-file. Apical gauging was performed by using insertion k-file #35 file to the full working length till it reaches the WL passively and does not extend beyond the apex after gentle finger pressure. Finally, irrigation was performed with 3ml of 5.25% NaOCl using #30-gauge side vented needle and adjusted 1mm shorter than the working length (0.26 mL/s) followed by 3ml 17% (EDTA) for 1 min. Finally, 3ml normal saline was used to flush the canal. The canals were dried with #35.04 paper points, avoiding complete drying to retain the moisture in the canal needed for the setting of the CSBS sealer⁽¹⁶⁾.

Root Canal Obturation

Obturation was performed using AH Plus Bioceramic sealer. The samples were randomly assigned to two equal groups based on the obturation technique:

Group 1: Single cone technique; Group 2: Cold lateral compaction technique;

In the single cone group, gutta percha cone #35 taper 4 was fitted in the canal to the working length and confirmed by radiograph. In accordance with the manufacturer's specifications, the sealer was injected with a syringe after the tip was placed in the midpoint of the working length. The sealer was injected until it was visible at the canal orifice. The master cone was placed to the full working length. Excess gutta-percha was removed from the orifice with a heated plugger, then condensed with a cold plugger.

In the cold lateral compaction group, a master gutta-percha cone sized #35.04 was fitted in the canal to the working length and confirmed by radiograph. A #25 spreader was selected that reaches within 3-4 mm shorter than the working length. The sealer was also injected using the same method as in the single-cone group. The master cone was placed to the full working length, and lateral compaction was performed with accessory #20 gutta-percha cones until no more cones could be added. Excess gutta-percha was removed from the orifice and then vertically condensed with a cold plugger. The quality of obturation was evaluated based on radiographs taken in the bucco-lingual and meso-distal directions. Samples that demonstrated voids, under- or over-filling were replaced with new one. The canal orifices were sealed with glass ionomer interim restoration. The samples were placed in an incubator at 37°C and 100% humidity for 3 weeks to allow the sealer setting.

Measurement of obturation material before retreatment procedure

Before retreatment, digital periapical radiograph and CBCT were performed to measure the amount of the obturating material. This measurement was performed by independent evaluator unaware of the aim of the study.

Digital Periapical Radiographic Evaluation

Digital periapical radiographs were taken in two standardized projections using the customized radiographic device previously described: frontal (buccolingual) and proximal (mesiodistal). Each radiographic image was exported and analyzed with ImageJ software (Wayne Rasband, National Institute of Health, USA). The image was magnified up to 100x and based on different opacity, the obturation material border was traced manually. The amount of the obturation material was measured and expressed in mm². These measurements were considered the pre-operative radiographic measurements and were termed P1_{frontal} and P1_{proximal}.

CBCT Evaluation

CBCT scans were performed using a Planmeca ProMax 3D Classic device (Planmeca, Helsinki, Finland) with a voxel size of 0.076 mm, a 4.5×4.5 cm field of view, 88 kV, and 10 mA. The samples were placed in custom acrylic blocks to ensure a standardized position for the scans.

The volume of the obturation material was measured using DDS-Pro software (version 2.22.0_2024 (c) JST Sp. 2024. Częstochowa, Poland). The threshold was adjusted to perform semi-automated segmentation to define the region of interest, which was the obturation material. Manual segmentation was performed when needed. This measurement was considered the pre-operative CBCT measurement and was termed C1.

Removal of obturation material

Glass ionomer interim restoration was removed using ultrasonic tip (GD1) under copious water. The obturating material was removed in two stages:

Stage 1: D1, D2, and D3 RT Gold retreatment rotary files (SuperFile® Shenzhen Superline Technology Co., Ltd. China)

The first file used was D1 file, size #30 with 9% taper, used for the coronal third for the first 5 mm. This was followed by the D2 file, size #25 with 8% taper, which was used for the middle third up to 10 mm from the reference point. Finally, the D3 file, size #20 with 7% taper, was used for the apical third to the full working length. These files were used in continuous rotation, in a picking motion for 2-3 mm amplitude, Canal patency was established using k-file #10. Between each file irrigation was done using 2ml of 5.25% NaOCl with #30-gauge side vented needle. Torque and speed settings were set according to the manufacturer instructions (speed:350 RPM and torque:2N) and each file was used for a single sample.

Stage 2: Conventional Rotary Shaping Files

AF Blue rotary files (Fanta, Jiading District, Shanghai, China) were used in the sequence of #25.04, #30.04, and #35.04. These files were used in a pecking motion till full working length in a single stroke then brushing against buccal and lingual walls three times each. Eventually, a #40 file was utilized up to the full working length. The procedure was considered complete when last file reaches the full working length for once⁽¹⁷⁾. Between uses of each file, 2 mL of 5.25% sodium hypochlorite was delivered via a #30-gauge side-vented needle during irrigation. The preparation device speed and torque settings were adjusted based on the manufacturer's instructions (2 N/cm² -350 RPM). Each instrument was single-use per sample.

The time taken to reach working length and achieve patency was recorded in seconds using an electronic stopwatch. The stopwatch was started to record the time when the file was placed in the canal. The stopwatch was stopped when apical patency was

achieved with a #10 K-file. Time needed for irrigation and changing rotary files was not recorded.

Measurement of Remaining Obturation Material

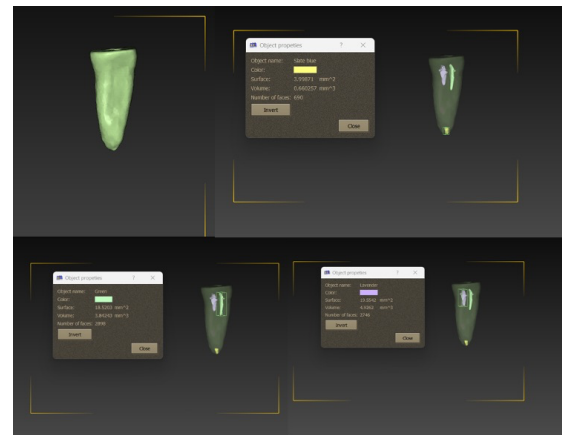
Following the completion of the retreatment procedure, the ROM was evaluated using digital periapical radiography, CBCT as well as direct visualization with a DOM. This measurement was performed by independent evaluator unaware of the aim of the study.

Digital Periapical Radiographic Assessment

Each sample was radiographed in both frontal and proximal projections. The radiographic images were analyzed with ImageJ software, with each image viewed at up to 100× magnification, and the remaining obturation material's border was traced manually. The amount of the ROM was measured individually and expressed in mm² Figure (2). The total area of the ROM was calculated and represented in mm². This measurement was termed **P2_{frontal}** for the frontal view and **P2_{proximal}** for the proximal view to be used later for the following procedure.

Figure 2. Photograph of the ImageJ software showing measurement of the ROM.

CBCT Assessment



Post-retreatment scans were accomplished with the same previously mentioned scanning protocol; Volume of the ROM was measured individually and expressed in (m³) using the same method mentioned previously. The total amount in the whole canal was calculated and coded as (**C2**) to be used later for the subsequent procedure.

Dental Operating Microscope Assessment

Following the CBCT and radiographic evaluations, the samples were sectioned longitudinally in meso-distal direction. Under 6x magnification, two longitudinal grooves were performed with a diamond disc (0.3 mm diameter) on the mesial and distal surfaces of the samples. These grooves were deepened without penetrating the root canal lumen, and the roots were then splitted into two halves using a chisel and mallet. Finally, the two halves were embedded in gypsum mold with graduated ruler to prepare the sample for evaluation under DOM.

Each portion was then evaluated under the DOM at 15× magnification. A custom-made metal

frame was used to fix the working distance between the sample and the DOM. Each portion was then photographed with a digital camera mounted on DOM, and the images were exported to a laptop and analyzed with Image J software to measure the ROM and area of total canal space. The image was magnified up to 100x then the remaining obturation material's border was traced manually. ROM was outlined and measured in mm² for each portion Figure (3). The total area of ROM was calculated and assigned the code of R1 and R2. The border of the canal space for each half was outlined and measured in mm² using the same method and coded as S1 and S2 for both halves. No attempt to distinguish between gutta percha and sealer.

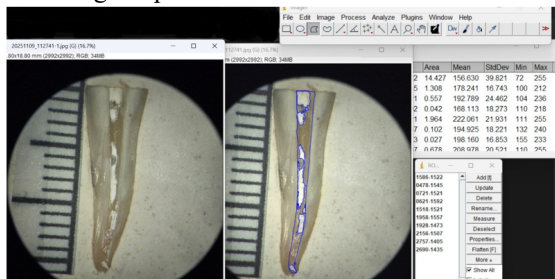


Figure 3. Photograph showing the remaining obturating material measurement using ImageJ

Data collection.

Digital periapical radiograph

The percentage of the remaining obturating material in each sample for each view (frontal and proximal) was calculated using the following equation:

$$\text{percentage of ROM} = \frac{\text{Amount of ROM (P2)}}{\text{amount of obturation material (P1)}} \times 100$$

CBCT

The percentage of the remaining obturating material in each sample was calculated using the following equation:

$$\text{percentage of ROM} = \frac{\text{Amount of ROM (C2)}}{\text{amount of obturation material (C1)}} \times 100$$

Dental operating microscope

The total measurement of all remnants for both halves was calculated as R1 + R2. The total canal space for both halves was calculated as S1 + S2. Then, the percentage of the remaining obturating material in each sample was calculated using the following equation:

$$\text{percentage of ROM} = \frac{\text{Amount of ROM (R1 + R2)}}{\text{Total Canal space (S1 + S2)}} \times 100$$

Statistical Analysis

Numerical data were explored for normality by checking the distribution of data using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Percentage of ROM data showed non-normal (non-parametric) distribution while time till patency data showed normal (parametric) distribution. Data

were presented as mean, standard deviation (SD), median and range values. For non-parametric data, Friedman's test was used to compare between different methods of assessment in each group. Dunn's test was used for pair-wise comparisons when Friedman's test is significant. Mann-Whitney U test was used to compare between the two groups (single cone and cold lateral compaction group). Agreement between methods was assessed using Cronbach's alpha and Intra-Class Correlation Coefficient (ICC). For parametric data (time till patency), Student's t-test was used to compare between the two groups. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Results

1. Comparison between the single cone group and the cold lateral compaction group in terms of the percentage of remaining obturation material.

There was no statistically significant difference between the single-cone and cold lateral compaction groups in the percentage of remaining obturation material using any of the assessment methods, with P-values of 0.892, 0.808, 0.957, and 0.829, respectively, and Effect sizes of 0.043, 0.077, 0.017, and 0.068, respectively. Table 1.

Table 1. Showing the results of the Mann-Whitney U test for comparison between the percentage of remaining obturation material of the two groups

M	Single cone (n =					Cold lateral					P	E
et	M	M	M	M	S	M	M	M	M	S	-	
h	e	i	a	e	D	e	i	a	e	D	v	
o	d	n	x	a		d	n	x	a		D	a
d	d	n	x	a		d	n	x	a		I	
C	1	1	6	2	1	1	1	6	2	1	0	0
M	1	3	6	2	1	2	3	6	2	1	0	0
R	1	1	6	2	1	1	1	5	2	1	0	0
a	7	.	1	1	5	7	.	6	0	2	.	.
R	2	2	6	2	1	2	3	5	2	1	0	0
a	3	.	0	6	4	3	.	8	5	1	.	.
di	.	3	.	.	.	.	7	.	.	.	8	0

*: Significant at $P \leq 0.05$

2. Comparison between the single cone group and the cold lateral compaction group in terms of time till patency

The single-cone technique group showed a statistically significantly longer time to patency than the cold lateral compaction technique group (P -value = 0.002, Effect size = 1.032). Table 2.

Table 2. Showing the results of Student's t-test for comparison between the time till patency (seconds) of the two groups

Single cone (n = 20)		Cold lateral compaction (n = 20)		P - value	Effect size (d)
Mean	SD	Mean	SD		
130.1	29.9	101.7	24.8	0.002*	1.032

*: Significant at $P \leq 0.05$

3. Comparison between methods of evaluation

A. Percentage of ROM in SC group

Pair-wise comparisons between methods revealed that there was no statistically significant difference between percentage of ROM measured by CBCT, DOM and Proximal view of PA; all showed statistically significant lower percentage of ROM compared to frontal view of PA. (P -value <0.001, Effect size = 0.533).

Regarding agreement between the different methods, there was substantial agreement between methods with Cronbach's alpha = 0.994 and Intra-Class Correlation Coefficient (ICC) = 0.975. Table (3)

Table (3) showing the results of Friedman's test for comparison between percentage of ROM of SC group and results of Cronbach's alpha and Intra-Class Correlation Coefficient (ICC) and its 95% Confidence Interval (95% CI) for agreement between methods

Meth od	Me dia n	Mini mu m	Max imu m	M ea n	S D	P - val ue	Ef fe ct siz e (w)
CBC T	19. 6 ^B	1.7	64.8	23	5. 9		1
Micr osco pe	19. 9 ^B	3.3	63.4	23 .5	1 5. 3	<0. 001 *	0. 53 3
Radi ogra ph (Prox imal view	17. 8 ^B	1.9	61.4	21	1 5. 2		

)							
Radi							
ogra							
ph							
(Fron	23. 1 ^A	2.3	60.3	26 .4			1 4. 3
tal							
view							
)							

Cronbach's alpha 0.994

ICC 0.975

95% CI 0.951 – 0.989

*: Significant at $P \leq 0.05$, Different superscripts indicate statistically significant difference between methods

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B. Percentage of ROM in CLC groups.

Pair-wise comparisons between methods revealed that the frontal view of digital PA and DOM showed statistically significant higher percentage of ROM than CBCT and proximal view of digital PA. There was no statistically significant difference between the frontal PA and DOM nor between CBCT and proximal PA. (P -value < 0.001 , Effect size = 0.483). As regards agreement between the four methods, there was substantial agreement between methods with Cronbach's alpha = 0.991 and Intra-Class Correlation Coefficient (ICC) = 0.965. Table (4).

Table (4): showing the results of Friedman's test for comparison between percentage of ROM of CLC group and results of Cronbach's alpha and Intra-Class Correlation Coefficient (ICC) and its 95% Confidence Interval (95% CI) for agreement between methods

Meth od	Me dia n	Mini mu m	Max imu m	M ea n	S D	P- val ue	Ef fe ct siz e (w)
CBC T	18. 5 ^B	1.7	60.8	21 .5	1 2. 7		
Micr osco pe	21. 5 ^A	3.9	63.1	23 .1	1 2. 6		
Radi ogra ph (Prox imal view)	17. 6 ^B	1.4	56.7	20 .8	1 2. 9	<0. 001 *	0. 48 3
Radi ogra ph (Fron tal	23. 7 ^A	3.7	58.6	25 .8	1 1. 4		

view

)

Cronbach's alpha 0.991

ICC 0.965

95% CI 0.932 – 0.984

*: Significant at $P \leq 0.05$, Different superscripts indicate statistically significant difference between methods

Discussion

Development of apical periodontitis in root-filled teeth have been related to improper canal disinfection and failing to control intraradicular infection occurs when sub standards root canal treatment is performed⁽²⁾. Consequently, adequate removal of all previous root canal obturation material is essential to gain access to all the components and ramifications of the root canal system to improve the efficiency of the irrigation and medication used for disinfection the root canal system^(5,6).

This study aims to evaluate the effect of obturation techniques on the remaining obturation material after retreatment of teeth filled AH+ Bioceramic sealer using two obturation techniques: single cone and cold lateral technique. Also, this study compares between digital periapical radiograph in frontal and proximal views, CBCT and DOM in evaluating remaining obturation material. Although Micro CT is a widely used method and considered a reference in the literature, their increased cost and unavailability prevented its inclusion in this study. Despite proximal view are extremely difficult to achieve clinically, it provides indispensable data on distribution of the ROM in the root canal system⁽¹⁸⁾.

The result of this study regrading remaining obturation material revealed that there is no statistically significant difference between single cone and cold lateral compaction technique. This was consistent across all evaluation methods. So, the first null hypothesis was accepted. This was in accordance with a precious study performed by Nour et al⁽¹⁹⁾. Conversely, other studies presented different findings and reported that obturation technique influenced the amount of ROM and SC technique leaves greater amount of sealer which might increase removal difficulty^(11, 20, 21). Nonetheless, different CSBS formulations were used and warm vertical compaction utilization might result in controversy results. Moreover, CSBS adhesion to dentin was not affected by obturation technique which support the findings of the current study⁽²²⁾.

With regards to retrievability, all samples in the present study regained apical patency. Previous studies documented the ability to regain working length and apical patency after retreatment of canals filled with gutta-percha and calcium silicate-based

sealers, provided that gutta-percha was extended to the full working length^(21, 23-25). Oppositely, other studies revealed different results and reported that CSBS might block the apical part hindering regaining working length and achieving patency⁽²⁶⁻²⁸⁾. However, most these studies intentionally placed the gutta percha 1.5 to 2 mm shorter than the WL in an attempt to mimic the retreatment situation. This approach might contribute to contradictory results.

The time to regain apical patency was used to evaluate the ease of removal of the filling material and the retrievalability of the sealer. The findings of the present study indicate that the single-cone technique took considerably longer to achieve patency than the cold lateral compaction technique. Other studies reported that single cone technique required less time^(11, 29). However, these studies employed warm vertical compaction versus single cone technique which was not the issue in our study. Also, different CSBS formulations was found to have different duration⁽³⁰⁾. Although this difference was statistically significant, the time difference was small and may have limited clinical relevance.

Concerning the comparison between different evaluation methods of ROM, in SC group, the frontal view of digital PA radiograph showed significantly higher percentage of ROM than the CBCT, DOM and Proximal view of digital PA, with no significant difference found between them. In CLC group, the frontal view of digital PA radiograph and DOM showed significantly higher percentage of ROM than CBCT and proximal view of digital PA. There was no significant difference between the frontal PA and DOM nor between CBCT and proximal PA. Therefore, the first null hypothesis was rejected.

The higher results obtained from frontal view of PA in both obturation techniques may be due to the oval nature of the premolar root canal space. Therefore, the canal space observed in the frontal view is less than that in the proximal view. So, this difference result in higher amount of obturation material observed in the proximal view consequently result in less percentage while the ROM is the same in both views.

In CLC technique, the direct visualization by DOM showed significantly higher ROM than PA proximal and CBCT. This findings can be explained by ability of DOM to visualize even small remnants of ROM while occasionally in 2D or 3D radiograph, thin and small remnants of ROM couldn't be visualized due to low radiographic contrast which is therefore couldn't be distinguish from dentine⁽³¹⁾.

The results of this study regarding PA radiograph versus DOM/direct visualization are contradictory to the results reported by other studies⁽³²⁻³⁶⁾. These studies used conventional PA radiograph in their evaluation process⁽³²⁻³⁴⁾. the other study didn't

evaluate the two part of root after sectioning procedure and evaluated only the portion that contains the largest obturation material consequently resulted in over estimation of the ROM by DOM⁽³⁵⁾. In the current study, both parts of the root were subjected to the evaluation process which give more realistic representation of the ROM. Additionally, digital PA radiograph was used which offer several benefits over conventional radiograph, these include superior resolution ,diversity of enhancement tools and significantly fewer measurement errors than film-based images especially with growing advancement in imaging technology⁽³⁷⁾. The contradictory findings to the current study reported by by Chropp et al⁽³⁶⁾ is also due to different in methodology in which the evaluation step carried out by undergraduate students which might question their qualification to accurately evaluate the ROM. Moreover, an extremely subjective score sheet was used for the assessment of ROM instead of quantitative measurement that might contribute to different results. On the other hand, no difference between digital PA and direct visualization was reported by Kalyoncuoğlu et al (2023)⁽¹⁸⁾ who compared the digital PA with endoscopy which is a direct visualization technique without sectioning. In this study, proximal PA revealed similar result to DOM in single cone group while frontal view revealed higher due to previously mentioned justification.

The results of CBCT versus DOM/direct visualization are contradictory to the results obtained by by Marfisi et al.⁽³⁸⁾ and Alouda et al.⁽³⁹⁾. Both studies showed higher ROM in CBCT than DOM while in the current study the results were similar in SC group while was higher in CLC group. This controversy can be explained a critical difference in the methodology. In the opposing studies, only one half of root was chosen for the direct visualization examination. This approach might not represent the actual amount of the ROM and moreover this approach is subjected to selection bias⁽¹²⁾. Furthermore, the smaller voxel size (0.075 µm) used in this study to the voxel sized employed the opposing studies (0.1 µm and 0.2 µm) which might contribute to different results as image quality and similarity to real condition was improved when using smaller voxel size⁽⁴⁰⁾.

A limitation of this study This study was conducted on a relatively simplified, single-rooted, straight canals. Thus, the results may not apply to other complex clinical scenarios, such as curved or irregular oval canals in multi-rooted teeth. Also, a micro-CT was not used so its advisable for the future studies to include Micro-CT to provide more precise three-dimensional analysis of the remaining obstruction material. Further studies should consider the effect of warm obturation methods, since heat is used in many obturation systems, and may influence the behavior and removal of calcium silicate-based sealers.

Conclusions

Within the limitations of this study, Single cone and cold lateral compaction technique don't carry significant impact on remaining obturation material during retreatment procedure. The single cone technique required significantly more time to achieve apical patency than the cold lateral compaction technique. Reaching full working length and achieving apical patency is feasible when using AH+ Bioceramic sealer. Additional information regarding the distribution and extent of remaining obturation material may be obtained through proximal periapical radiographic views. CBCT and proximal view of PA is the most correlated methods recommended for ROM evaluation.

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