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Comparative analysis between resin-based root canal sealer and recent bioceramic-based root canal sealers using MicroCT, film thickness, and solubility

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ABSTRACT

Background: This study is aimed at evaluating the sealing quality of the single cone obturation technique with resin-based root canal sealers (ADseal root canal sealers, control group) and the novel hydraulic bioceramic-based sealers (Fill Root ST and AH Plus Bioceramic sealers). The assessment was performed by micro-CT void analysis. In addition, film thickness and solubility of the sealers were also evaluated.

Materials and methods: Voids were evaluated on clear acrylic resin blocks with a standard artificial root canal model using micro-CT. Physical analysis of the sealers assessed film thickness and solubility. Statistical analysis included one-way ANOVA with Tukey's post-hoc test for multiple comparisons and repeated measure ANOVA for related samples.

Results: The AH Plus Bioceramic Sealer exhibited the least canal voids (5.70 %), while the Fill Root ST had intermediate voids, and ADseal had the highest ($p < 0.001$). The coronal third had the most voids, followed by the middle and apical thirds ($p < 0.001$). AH Plus Bioceramic Sealer had the thinnest film thickness (19.3 μm), followed by Fill Root ST (42.7 μm), and ADseal (81.7 μm) ($p < 0.001$). In solubility, ADseal had the lowest (0.9 %), Fill Root ST the highest (2.4 %), and AH Plus Bioceramic intermediate (1.5 %) ($p < 0.001$).

Conclusions: The bioceramic-based sealers (Fill Root ST and AH Plus Bioceramic) showed superior performance compared to ADseal in terms of void formation and film thickness, with voids most frequent in the coronal third and least in the apical third.

1. Background

Obtaining a fluid-tight seal of the entirety of the root canal system is the principal purpose of root canal obturation in order to prevent leakage and hence secondary infection.[1] Three-dimensional hermetic filling is critical to filling and sealing the whole root canal system, particularly in the apical third of the canal. Recently, tapered gutta-percha cones were introduced in the market that have the same diameter and conicity matched to the final used shaping file.[2,3] Regardless of the obturation technique used, the root canal sealers are compulsory to fill the spaces that exist because of the dimensional dissimilarity between the gutta percha points and the root canal wall.[4] Several obturation techniques have been proposed, addressing a void-free obturation of the endodontic space with proper adaptation of the filling material to the canal.[5]

Creating effective endodontic therapy relies on ongoing improvements in both root canal instruments and materials [6–10]. The continuous advancement of bioceramic technology providing an interesting development in endodontic sealer materials.[11,12] Bioceramic sealers provide favorable properties, including bioactivity [12–14] cytocompatibility,[15,16] favorable physical and chemical properties,[12,17] excellent flow,[11,18] and an antibacterial effect.[19]

The impressive biological and physicochemical properties of bioceramic sealers have led to a shift away from the traditional gutta-percha-based obturation method to the single-cone technique.[20] This approach relies on hydraulic condensation; a pre-fitted gutta-percha cone is placed into a canal filled with bioceramic sealer, creating hydraulic pressure that enables even distribution of the endodontic sealer and reduces voids in root canal filling, providing a high-quality seal.[21] This technique is not only efficient and cost-effective but also minimizes the risk of root fractures that can occur with lateral or vertical compaction. Moreover, it allows for more easier for retreatment if

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necessary.[20]

The sealing ability can be tested with micro-leakage tests[22] or with sectional analysis tests such as scanning electron microscopy, confocal laser scanning microscopy, and micro-computed tomography (micro-CT). Micro-CT is considered an effective technique for the qualitative and quantitative evaluation of the quality of root canal obturation.[23]

Micro-CT has proven to be a reliable, non-destructive tool for detecting voids and assessing the adaptation of obturated root canals. It provides high-resolution, three-dimensional imaging, enabling precise evaluation of filling material consistency and canal wall adaptation, which is crucial for identifying potential risks and ensuring the long-term success of root canal treatments.[23]

Film thickness is a crucial characteristic of a root canal sealer, as it guarantees the ideal sealing capacity of the root canal systems, thus decreasing the presence of voids.[12,24] Additionally, it influences how easy the sealers are to handle.[25] Moreover, for ideal root canal sealers to provide perfect sealing, the main requirement is insolubility.[26] Furthermore, the high solubility of sealer materials can potentially weaken their integrity and affect their survival rates.[27]

Nonetheless, this single cone obturation technique still lacks evidence regarding the efficiency of sealing the root canal system, especially for this newly introduced hydraulic bioceramic sealers. Hence, this study aimed to compare and evaluate the sealing quality of single cone obturation technique with resin and hydraulic bioceramic sealers.

The voids were evaluated upon clear acrylic resin blocks with a standard artificial root canal model, using microcomputed micro-CT. Moreover, physical analysis of the sealers was performed to evaluate their film thickness and solubility. The null hypothesis was that there would be no difference between resin-based root canal sealers (ADseal root canal sealers) and the novel bioceramic-based sealers (Fill Root ST and AH Plus Bioceramic sealers) regarding void percentage, film thickness, and solubility.

2. Materials and Methods

The study was approved by the Research Ethics Committee of Faculty of Dentistry, The British University in Egypt (approval number for the study: 24024). All methods were carried out in accordance with relevant guidelines and regulations. The basic experimental sealers used throughout the present study with their chemical composition and their manufacturer are represented in Table 1. The groups are randomly distributed into three groups according to the material employed and each test (see Fig. 1).

Table 1
The chemical constituents of the root canal sealers used in the investigation.

Root canal sealers	Chemical composition[a]	Manufacturers
ADseal (resin-based sealer), (control group)	Poly(1,4-butanediol) bis(4-aminobenzoate) (30–40 %), Bisphenol A diglycidyl ether–bisphenol A copolymer (20–30 %), 2-Hydroxyethyl salicylate (15–20 %), Triethanolamine (<10), calcium oxide (<5 %).	Metabiomed, Cheongju, Korea
Fill Root ST (bioceramic sealer)	Zirconium oxide, dicalcium aluminosilicate with mean size around 10 μm.	Dental World, Molfetta, Italy
AH Plus Bioceramic sealer (bioceramic sealer)	Zirconium dioxide (50 %–75 %), tricalcium silicate (5 %–15 %), dimethyl sulfoxide (10 %–30 %), lithium carbonate (<0.5 %), thickening agent (<6 %)	Dentsply, De-Trey Konstanz, Germany

[a] The chemical composition concentration information, expressed as a percentage by weight (WT%), was taken from the corresponding Material Safety Data Sheets (MSDS).

2.1. Sample size calculation

The sample size calculation was based on a similar study [28–30]. With an alpha level of 0.05 and a power of 80 %, a sample size per group for each test was determined using G*Power software version 3.1.9.4 (Heinrich Heine University Duesseldorf, Duesseldorf, Germany). The indicated samples were 10 per group.

2.2. Micro-CT void analysis

2.2.1. Preparation of specimens

Thirty clear acrylic resin models (Dentsply Maillefer, Ballaigues, Switzerland) with an artificial canal were used. The artificial canal had a standardized length of 19 mm, 30° angle of curvature and 5 mm radius of curvature.

2.2.2. Root canal preparation

A patency K-file size 10 was inserted in the artificial canal till the file tip appeared flushing with the apical foramen; this was considered as the tooth length (TL), and then the working length (WL) was calculated by 1 mm subtraction from the full tooth length measurement. Mechanical preparation of the artificial canals was done using the ProTaper Next system (Dentsply Sirona, Maillefer, Ballaigues, Switzerland) in the following succession: XA, X1, and X2 at torque 2.5 N/cm and a rotation rate of 300 rpm using the X-Smart endodontic motor (Dentsply Maillefer, Ballaigues, Switzerland) #30, #35 and #40 with taper 0.04.

The Protaper Next, files were drawn into the canals with a vertical amplitude of 3 mm using a gentle pecking motion. Following every 3 pecking motions, the file was withdrawn, checked and cleaned of any debris. Throughout the shaping procedure, irrigation was administered into the canal with 3 ml of 2.5 % NaOCl, and canal patency was confirmed with K-file size 10.[31] The artificial canals were finally flushed using 5 mL of distilled water and then dried using absorbent paper cones. The root canals were dry enough without causing excessive dryness if the last 3–4 mm of the paper point tip were wet after the point removal.[32]

2.2.3. Samples obturation and division

After preparation, the artificial root canals were allocated randomly into three equal groups (n = 10) based on the type of sealer used in root canal filling. For each canal, a matched single cone size X2 (ProTaper NEXT Gutta Percha, Dentsply Sirona) was checked to have a good apical tug back.

Group 1: the matched single cone was fully coated with the resin-based sealer ADseal. Group 2: the matched single cone was used in conjunction with Fill Root sealer. Group 3: the matched single cone was used in conjunction with AH Plus bioceramic sealer.

All hydraulic sealers were injected into the coronal third of the root canals, followed by application of the matching cones coated with sealers. Excess gutta percha was trimmed using a heated instrument at the level of the root canal orifice, followed by slight compaction using a cold plugger. Every step was accomplished by an experienced operator under magnification of 8×. Following obturation all samples were stored for one week at 37 °C in 100 % humidity in an incubator (CBM, S.r.l. Medical Equipment, 2431/V, Cremona, Italy) to allow complete setting.[33] Fig. 2 represent the obturation of the clear acrylic resin models.

2.2.4. Micro-CT scanning and analysis

The specimens were scanned using micro-computed topography imaging system XT-H 225 (Nikon Metrology Inc., Brighton, MI, USA) to analyze the filling quality of root canal obturation.

2.2.5. Image acquisition

The acquisition parameters used were 90–110 kV, 80–110 μA, a voxel size of 10.459 μm, and a 500 μm Al filter. The parameters for

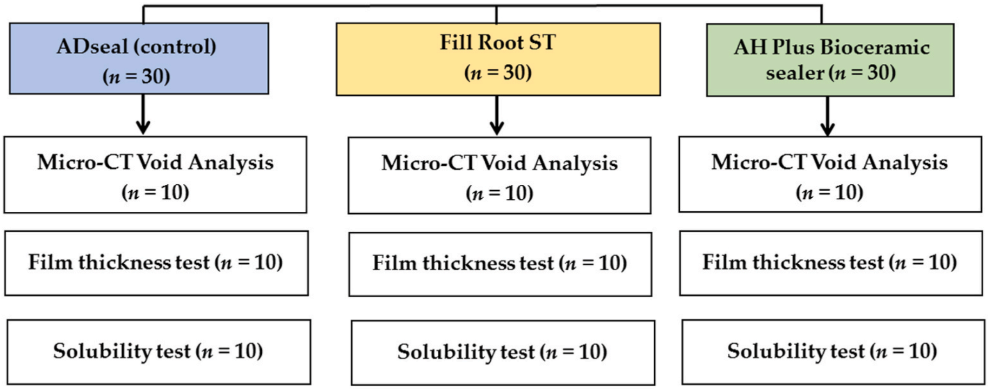

Fig. 1. Flowchart showing the various specimen groups.

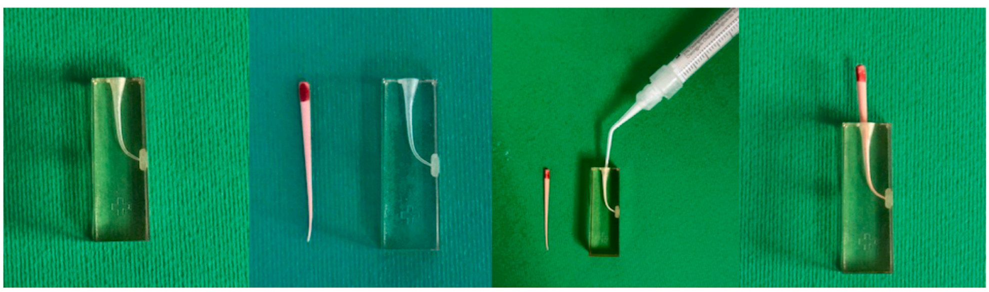

Fig. 2. Representative image of the root canal obturation of clear acrylic resin models.

reconstruction used were defined as the following: beam hardening correction was preset to index 2, noise reduction was preset to index 1, and the volume height was adjusted to 873-934-1856 pixels. The scanning process lasted around 33.4 min for each scan while rotating the sample just over 180° around the vertical axis. The exposure time of the camera was 708 ms, while the projection's total number was 720 for each scan with 4 frames per projection. All scans were subjected to flat field correction and geometric correction for random movement.[34]

2.2.6. Image reconstruction and quantitative assessment

The X-TEK CT Pro 3D (Nikon Metrology X-TEK CT Pro., version XT 3.1.11, Tokyo, Japan) software was used to reconstruct the digital data. Three-dimensional imaging and qualitative assessment of the obturation were performed with VG Studio software (VG StudioMax version, Version 3.4, Volume Graphics GmbH, Heidelberg, Germany). The volume of the voids and the filling material within the samples was calculated by the processing of the original greyscale images using VG Studio software (Version 3.4, Volume Graphics GmbH, Heidelberg, Germany). The root canal filling was calibrated to define the material, while air was calibrated to define the background. An entire object was designated as the region of interest, and the selected area was subsequently extracted. The volume of the material was calculated using surface determination. The internal porosities for each third of the root canal were calculated using porosity/inclusion analysis, and then the total volume was calculated in mm^3. The oral radiologist who performed the scanning and assessment was blinded to the groups.[35]

2.3. Film thickness test

Investigation of the film thickness of each root canal sealer was performed in accordance to the International Standard Organization (ISO) 6876:2012 instructions.[36] Two flat glass plate pieces, each measuring 200 × 10 mm and 5 mm thick, were positioned on top of each other. An electronic digital caliper (Digital Vernier Caliper, Mitutoyo, Japan) was used to measure the total thickness.

Every endodontic root canal sealer was made in accordance with the guidelines provided by the manufacturer. The lower glass plate was immediately covered with the upper glass plate after 0.5 cc of each sealer had been mixed. On the upper glass plate, a 150 N load weight was applied vertically for 180 ± 10 s. A digital caliper was used to measure the overall thickness of the plates, including the sealer, 10 min after the mixing time (7 min after the force was applied). The value of the film thickness was attained through subtracting the previous reading from the total thickness of the glass plates. By taking three readings and calculating the average, the mean film thickness value for each sealer specimen was determined.

2.4. Solubility test

In compliance with the International Standard Organization, the solubility test was conducted (ISO 6876:2012).[37] Each root canal sealer was filled into Teflon molds that were 1.5 mm tall and 7.75 mm in inner diameter to create a disc-shaped specimen.[24,38,39] The specimens were removed from the mold after being incubated at 37 °C for 24 h with 95 % relative humidity to set. They were then weighed (M1) using an analytical scale (Adam Equipment 4-digit precision weighing balance, UK) with a 0.001 g accuracy.[38]

After that, samples of each root canal sealer were suspended on nylon thread tied around it by small knot around the top edge of the samples in a closed plastic flask filled with 7.5 mL of distilled water. The flasks were then kept in an incubator set at 37 °C and 95 % relative humidity for two consecutive periods, which are seven and fourteen days. After being taken out of the incubator and dried using absorbent paper, the specimens stored for 1 day in a dehumidifying chamber.[24,40] The samples were then weighed again (M2). A percentage of the initial mass was used to represent the mass loss. The following formula was used to determine the percentage of root canal sealers solubility: (M1-M2)/M1X100 %[24,40,41]

Where M1 represents the specimens' starting mass and M2 represents their ending mass.[29,39]

2.5. Statistical analysis

Examination of the normality of the data was achieved by the Shapiro-Wilk test and the Kolmogorov-Smirnov test; the comparison between different groups was attained using the one-way ANOVA test, followed by Tukey's post-hoc test for multiple comparisons. Repeated measure ANOVA was used to compare between more than two groups (thirds) in related samples. Statistical analysis was conducted using SPSS 16.0 statistical software (SPSS Inc., Chicago, IL, USA). The significance level was set at P-value<0.05.

3. Results

The mean values of total voids total percentage (%) of different tested sealer groups are presented in Table 2. The inter-group comparison showed significant differences in the percentage of voids amongst the different sealers. The AH Plus Bioceramic Sealer had the least percentage of canal voids (5.70 %), while the Fill Root ST had an intermediate percentage of canal voids. Meanwhile, the ADseal root canal sealer displayed the highest percentage of canal voids ($p < 0.001$).

The mean values of total voids total percentage (%) of different tested sealer groups in different thirds are presented in Table 3.

The intra-group comparison showed that for all sealer groups, the coronal thirds had the highest percentage of voids, followed by the middle thirds and apical thirds, respectively ($p < 0.001$). The coronal thirds had the highest percentage of voids, followed by the middle thirds and apical thirds, respectively. However, a higher void percentage can be detected in the ADseal root canal sealer than in Fill Root ST. While the AH Plus Bioceramic Sealer had the least percentage of canal voids as shown in Fig. 3. In summary, the AH Plus Bioceramic Sealer offered the most consistent and effective seal, particularly in the crucial apical region, by achieving the lowest void percentage in all three sections and the best apical seal.

The mean values of the film thickness of the different tested sealer groups are presented in Table 4. Results showed a significant difference in film thickness between the three sealers. The AH Plus Bioceramic Sealer had the least film thickness (19.3 μm), while the Fill Root ST (42.7 μm) had an intermediate film thickness. Meanwhile, the ADseal root canal sealer displayed the highest film thickness (81.7 μm), ($p < 0.001$).

The mean values of the solubility percentage of the different tested sealer groups are presented in Table 5. Results showed a significant difference in the solubility percentage between the three sealers. The ADseal showed the least solubility (0.9 %), while the Fill Root ST displayed the highest solubility (2.4 %). Meanwhile, the AH Plus Bioceramic Sealer showed intermediate results (1.5 %), ($p < 0.001$).

4. Discussion

Recent improvements in endodontic materials have included bioceramic-based sealers made from a blend of zirconium oxide, calcium silicates, calcium phosphates, and calcium hydroxide. These sealers have hydrophilic qualities that enable setting reactions in a wet environment within the root canal, limiting shrinkage, and are readily applied in pre-mixed syringes Moreover, it promotes mineralization and they have enhanced biocompatibility.[42]

Modern trends in root canal obturation have turned towards the use of the single cone technique as it considered as simple, fast, and less technique sensitive procedure.[43] A matched gutta percha cone approach for root canal obturation with bioceramic sealers is used with no vertical or lateral compaction,[5,44] it assume to provides a lower the probability of procedural errors.[45]

Recent premixed bioceramic-based root canal sealers (Fill Root ST and AH Plus Bioceramic Sealer) have claimed to provide successful obturation results, especially with a single-cone approach, in addition to providing a favorable handling characteristic compared to other root canal sealers.[46]

An important measure for evaluating the quality of root canal filling is the absence of voids.[47] The presence of voids in root canal fillings is clinically significant because the pores and gaps that form can allow bacteria and their byproducts to penetrate.[35] Micro-CT was used to assess the quality of root canal filling. Micro-CT technology could be differentiates between the root filling materials, structure of the tooth and voids, providing optimum detection of the void in root fillings.[48] It considered as a non-invasive imaging technique, which delivers images with high-resolution and enables quantitative and qualitative analysis three-dimensionally across various grayscale levels.[49]

Anatomic standardization of root canal, in terms of canal length, diameter, angle and radius of curvature was achieved through utilization of clear acrylic resin blocks. ADseal resin-based sealer was selected as a control sealer because it is readily available and has a reported lower solubility rate [50–52].

The film thickness of the root canal sealers plays a crucial role. A thinner film improves how well the materials adhere to the canal wall, ensuring a proper seal. If the film thickness decreases, it can negatively affect the sealing of the root canal, leading to minimal microleakage.[24,53] Solubility is the process by which the surrounding fluids dissolve the material's components.[30] The insolubility of the root canal sealers is of great significance for successful root canal treatment through the creation of an intimate seal between the dentin wall and restoration.[40] If root canal sealers are highly soluble, they can create gaps both within the material and between it and the dentinal wall of the canal. This can lead to leakage from the surrounding tissues.[54]

The purpose of this study was to evaluate two premixed bioceramic-based root canal sealers with an epoxy resin-based root canal sealer in terms of voids percentage, film thickness, and solubility. The null hypothesis was rejected due to a significant difference found between resin-based root canal sealers (ADseal root canal sealers) and the new bioceramic-based sealers (Fill Root ST and AH Plus Bioceramic sealers) when comparing voids percentage, film thickness, and solubility.

The reduced voids in Fill Root ST and AH Plus Bioceramic Sealer may be attributed to the fact that they are a premixed bioceramic root canal sealers, which delivered in convenient syringe packaging. This eliminates the risk of errors in the powder-to-liquid ratio. Moreover, they provided with special injection tips designed for easy application directly into the root canal, which may reduce voids formation in the root canal filling.[55] The reduced voids in the AH Plus Bioceramic may be

Table 2
The mean, standard deviation (SD) values of total voids percentage (%) of different groups.

ADseal sealer (control)	Fill Root ST	AH Plus Bioceramic Sealer	P-value
$14.90^{c}\pm0.39$	$9.75^{b} \pm 0.17$	$5.70^{a} \pm0.21$	P = 0.001*

Means with different letters indicate a significant difference (P-value <0.05).

Table 3
The total void percentage results in different tested groups at various root canal sections (apical, middle, and coronal).

Root Third	ADseal Sealer (Control)	Fill Root ST	AH Plus Bioceramic Sealer	P-value
Coronal Third	8.90 ± 0.29 aA	4.00 ± 0.28 cB	3.40 ± 0.16 cA	<0.001*
Middle Third	3.80 ± 0.20 bB	3.70 ± 0.11 aA	1.70 ± 0.13 dB	<0.001*
Apical Third	2.20 ± 0.10 bC	2.10 ± 0.08 bC	0.60 ± 0.04 cC	<0.001*

The different small letters (a, b, c, d) indicate significant differences between groups within the same column, while the capital letters (A, B, C) indicate significant differences within the same row. Statistical significance was determined with a P-value <0.05.

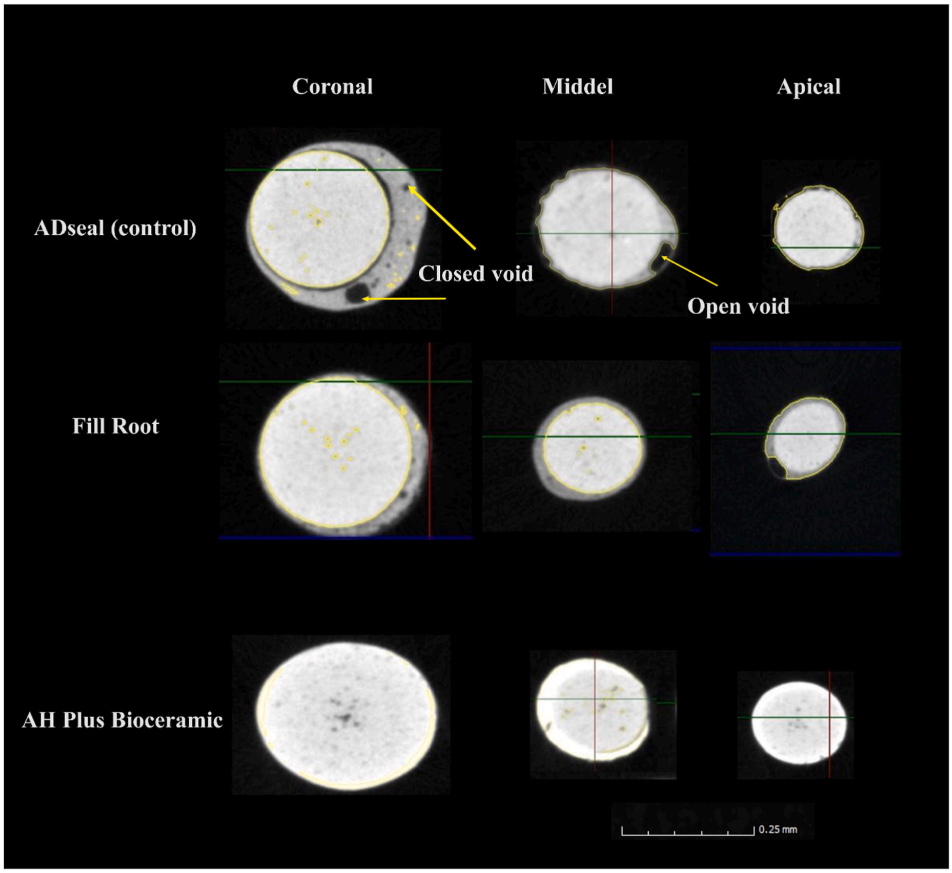

Fig. 3. Representative Micro-CT images of the three different root thirds (coronal, middle, and apical) demonstrated that for all sealer groups.

Table 4
Film thickness test (μm) of the different tested sealer groups.

ADseal sealer (control)	Fill Root ST	AH Plus Bioceramic Sealer	P-value
$81.7^a \pm 1.53$	$42.7^b \pm 2.52$	$19.3^c \pm 1.53$	P = 0.001*

Means with different letters indicate a significant difference (P-value <0.05).

Table 5
The mean values of solubility % of the tested sealers.

ADseal sealer (control)	Fill Root ST	AH Plus Bioceramic Sealer	P-value
$0.9^a \pm 0.1$	$2.4^b \pm 0.1$	$1.5^c \pm 0.1$	0.0001*

Means with different small letters in the same row indicate a significant difference. *Indicates a statistically significant difference (P-value <0.05).

due to their reported reduced particle size.[12] Our results agree Hedge et al.[56] and Gyulbenkiyan et al.[57] who reported that hydraulic sealers resulted in smaller gaps in comparison to epoxy resin-based sealers. The increased voids in ADseal root canal sealer can be attributed to the larger particle size and higher filler load, which contribute to reduced flow. Additionally, polymerization shrinkage stress may further exacerbate void formation, and enhance creation of flow.[58,59]

Regarding the intra-group comparison, our results indicated that the coronal thirds were associated with the highest percentage of voids, followed by the middle thirds and apical thirds, respectively. This can be attributed to the configuration of the root canals. The coronal third is wider, which increases the chances of sealer misfit and voids.[60] On the other hand, the apical third is narrower and more confined, allowing for better adaptation and less space for voids. Additionally, when using the single-cone technique, the lack of active compaction can lead to poor adaptation, particularly in the coronal area. In contrast, the apical third benefits from the hydraulic push provided by the master cone. It's also worth noting that the taper of the prepared canal is often greater than that of the master cone, especially in the coronal region, which can result in thicker layers of sealer and more voids. Furthermore, the cone tip fits perfectly in the apical area, which helps minimize the formation of voids. Lastly, using a larger amount of sealer in the coronal area may lead to more shrinkage and, consequently, more voids.[61,62]

AH Plus Bioceramic and Fill Root ST are both calcium silicate-based bioceramic root canal sealers known for their reduced film thickness.[63] However, the film thickness can vary between the two because of differences in their calcium content and the presence of other elements.[64] The lowest film thickness of AH Plus Bioceramic Sealer is probably due to their smaller particle size, which aligns with what the manufacturer has stated. Additionally, having a greater amount of zirconium (50–75 wt %) and a minimal number of thickening agents (<6 wt %), which might enhance the flow and help reduce the sealer's film thickness.[24,65] The higher film thickness of ADseal root canal sealer may be attributed to the larger particle size and resin load compared to bioceramic sealers. Moreover, the epoxy resin matrix may provide earlier viscosity. These characteristics limit the spread of the material, thereby increasing its film thickness.[63]

Following the ISO 6876:2012 guidelines for endodontic sealers, the highest solubility allowed is 3 % by mass.[37] Within this range, all of the sealers that were tested for this study; ST Fill Root (2.4 %), AH Plus Bioactive (1.5 %), and AD Seal (0.9 %) showed acceptable clinical performance in terms of solubility. The ADseal root canal sealer (control) demonstrated the lowest solubility, likely because of its resinous epoxy-based composition. This sealer forms an insoluble cross-linked polymerized resin matrix, which results from the polymerization of amine groups with epoxide groups.[66,67] These results align with the findings of Song et al. and Abu Zeid et al..[68,69] On the other hand, the AH Plus Bioceramic sealer exhibited moderate solubility, possibly due to its higher content of stable crystalline zirconium,[24] along with the fact that hafnium oxide is insoluble in water.[70]

The current study does have some limitations, such as the absence of *in vivo* validation, short testing duration, and differences in the surrounding conditions compared to real clinical situations. Additionally, it would be beneficial to conduct further research on the particle size of root canal sealers. Other physical properties, like viscosity, setting time, and radiopacity, should also be evaluated for a more comprehensive understanding.

5. Conclusions

In conclusion, the bioceramic-based sealers, Fill Root ST and AH Plus Bioceramic sealers, established superior performance in root canal obturation compared to the ADseal resin-based root canal sealer as regards void formation and film thickness. Additionally, voids are most frequent in the coronal third due to canal geometry, sealer flow behavior, and absence of compaction forces. The apical third consistently shows the fewest voids because of better fit and hydraulic movement of sealer.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Consent for publication

Not applicable.

Ethics approval and consent to participate

This *in vitro* study received ethical approval from the Research Ethics Committee of Faculty of Dentistry, The British University in Egypt (approval number for the study: 24024). All methods were carried out in accordance with relevant guidelines and regulations.

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Not applicable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Abbreviations

Micro-CT: Micro-Computed Tomography; WL: Working length; ISO: International Standard Organization; SD: Standard deviation;

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