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Original Article

Evaluation of dimensional changes in EndoSeal mineral trioxide aggregate and AH Plus sealers using micro-computed tomography imaging

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ABSTRACT

Background: Optimal dimensional stability is required for successful root canal treatment. A sealant called EndoSeal mineral trioxide aggregate (MTA) was recently introduced to the market due to its favorable physical and chemical properties. On the other hand, AH Plus (AHP) is considered the gold-standard seal.

Materials and Methods: In this *ex vivo* quasi-experimental study, 24 single-canal premolars extracted from humans were cleaned and shaped with a motorized and rotary file, then that is divided into two groups. The teeth of each group were filled with gutta F3 and each type of sealant. The teeth were scanned by a micro-computed tomography device after 24 h. After 7 days of storage in phosphate-buffered saline solution, the samples were re-scanned. Data were analyzed using SPSS software (version 21). Descriptive data were presented as frequency, percentage, mean, and standard deviation. The Shapiro–Wilk and Kolmogorov–Smirnov tests were used to investigate the normality of the data. The Mann–Whitney test was used to compare the two groups, and the differences were ultimately not significant. The level of significance was set at 0.05 ($P < 0.05$).

Results: The mean differences between sealer volumes before and after the intervention were not significantly different between the two groups indicating that the EndoSeal MTA sealer is not inferior to the gold-standard root canal sealer, AHP.

Conclusion: EndoSeal MTA can be considered a reliable sealer in endodontic treatments and be subjected to further investigation.

Key Words: Dental pulp cavity, epoxy resin-based root canal sealer, mineral trioxide aggregate, X-ray microtomography

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INTRODUCTION

The long-term success of root canal treatment depends not only on the correct cleaning and formation of the root canal but also on sealing it with the appropriate sealer.[1] According to Grossman, dimensional stability is one of the characteristics of an ideal sealer.[2] Some sealers simultaneously decrease and increase

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in volume due to solubility or water absorption. The magnitude of these dimensional changes creates gaps and pathways between sealer-dentin or gutta-sealer contact surfaces, providing enough space for microorganisms to enter the root space.[3]

A mineral trioxide aggregate (MTA)-based calcium silicate sealant named EndoSeal MTA (EDS) has recently been launched that does not have some of the limitations of MTA as a sealant and can be used directly in syringes.[4,5] Easy application, the possibility of removal after hardening, and the ability to penetrate narrow root canals are among the features of this sealer.[6,7]

EndoSeal MTA has gained popularity for root canal injection due to its properties of intratubular biomineralization, high radiopacity, low dissolution in contact with tissue fluids, expansion on setting, and excellent viscosity. In addition, EDS has a fast setting time and high washing resistance due to the fine silica particles without the need for chemical accelerators.[4,5]

AH Plus (AHP) is another epoxy-based sealer that has been identified by various studies as the gold-standard sealer with excellent dimensional stability.[8,9] AHP has good fluidity, seals dentin walls well, and has low dissolution and setting time.[10,11]

However, according to some studies, the hardness of the bond with gutta-percha and the disruption of the bond with the canal walls in the presence of saliva reduce the sealing properties of this sealer during clinical use.[8,12]

To assess dimensional changes, the ISO guidelines (ISO 6876:2012 2012) have been used in many studies, which recommend immersing a cylindrical specimen of a standardized sealer in water after the complete setting of the cement (or at least after 70% of the initial setting time).

However, this experimental model does not replicate the clinical situation precisely due to factors such as the difference in the shape of the samples with the shape of the filling cone, the difference in the maintenance solutions with the tissue conditions, the linear measurement, and the length of the short-term measurement of the conditions.[13] Recently, a micro-computed tomography (micro-CT) method has been used to measure the dimensional stability, dissolution, and porosity of sealers.

Micro-CT is a nondestructive, three-dimensional imaging technique that has been used to assess the morphology, internal structure, density of mineralized material, and porosity of root canal filling materials. The high resolution of micro-CT imaging has made it possible to create 3D models with high imaging properties from laboratory samples (*ex vivo*).

Since dimensional stability is very important for successful root canal treatment and the fact that few studies have been conducted on the dimensional stability of EDS sealer with precise methods like Micro-CT, this study aimed to compare the dimensional variation of MTA EndoSeal with AHP gold-standard sealer using micro-CT imaging method.

METHODS

Sample collection and preparation

This quasi-experimental *ex vivo* study was approved by the Ethics Committee of Mazandaran University of Medical Sciences, Sari, Iran (IR.MAZUMS.REC.1399.7004). A total of 24 extracted single-canal human premolars with similar anatomy were collected.

The sample entry criteria were: (1) premolar single-canal human teeth, (2) having intact roots without internal or external resorption, and (3) having a straight root with appropriate length without curvature in the apical third.

Exclusion criteria included: (1) the presence of fracture or decay under the cementoenamel junction, (2) previous tooth canal filling, (3) root canal calcification, (4) occurrence of errors during operation, including perforation, transport, or breakage of the device inside the canal, (5) void in the obturation area, and (6) filling shorter or longer than the working length (WL).

After tooth extraction, the surfaces of the collected teeth were cleaned with gauze from soft tissue and mass debris. For surface disinfection, teeth were soaked in sodium hypochlorite 5.25% (Nik Darman, Iran) for 24 h. The teeth were then stored in a container of distilled water at room temperature until the next use. Before starting the study, the crown cement–enamel junction was trimmed with a diamond disc (DFS-Diamon®, Germany) so that a root length of at least 10 mm was retained. All prepared teeth were then stored twice in distilled water at room temperature pending further testing.

Preparation of root canal

First, a 1 mm size K file #10 (MANI, Japan) was removed from the edge of the apical foramen of the tooth to ensure that the canal edge pathway was open. The WL was then taken to be 1 mm above the border of the tip hole. A micromotor rotation system (Marathon, Korea) and a rotation file (Super Files 3, Denco, China) were used for root canal preparation.

Files S1, Sx, S1, S2, S3, F1, F2, and F3 were used according to manufacturer's recommendations. To do this, S1 and Sx files were initially used for coronal enlargement and access to WL. Each of the S1, S2, S3, F1, F2, and F3 files was then used on WL with reciprocating motion (within 3 mm range). After using each file, 20 ml of 25.5% sodium hypochlorite was used to clean each canal.

Finally, 3 ml of 17% EDTA solution (Morvabon, Iran) was used for 3 min, and 1 mm of sodium hypochlorite was used to thoroughly wash the canal to remove any remaining debris or smear layer. The canal was then washed with distilled water to remove the residues of the washing agents. Eventually, a #10 K file was inserted into the end of the root canal to check the validity of the root canal, and the specimen was placed in distilled water until the next use. The same operator prepared all samples (the process was performed by the author M.D. who was already trained in this field).

Canal filling

First, the root canal was completely dried with paper cone #35 (Meta Biomed, Korea). One sealant from EDS (Multi, Korea) and AHP (Dentsply, USA) was used in each group. The sealer was made by the same operator according to the manufacturer's instructions (M.D.). An AHP sealer was prepared and placed in the root canal, and an EDS sealer was injected into the root canal up to the stump according to the manufacturer's instructions. #35 gutta-percha (Meta Biomed, Korea) was then inserted into the canal to the end of the WL and occluded using the single-cone method.[14] Before the coronal section, up to 2 mm of excess gutta-percha was removed with a hot plugger, and the root canal filling material was compressed in the coronal region with a cold plugger. The 2 mm root canal space was then filled with a light-curing glass ionomer restorative (SDI, USA).

Micro-computed tomography scans

A periapical radiograph was obtained to check the adequacy of the filling immediately after filling. The catalogs indicate that EndoSeal MTA® setting time is 12.31 h[15] and AHP® setting time is 8 h.[16] Provided that the filling condition was suitable after 24 h, the teeth were scanned using micro-CT scanning at Matin Behin Negareh Imaging Technology Center (Tehran-Iran). Before imaging, the teeth in the EDS group were coded with odd numbers and the letter M, and the teeth in the AHP group were coded with even numbers and the letter A.

To perform micro-CT scanning, the teeth were inserted into the device in threes [Figure 1]. The samples were then transferred to the phosphate-buffered saline (PBS) solution and placed in the incubator at 37°C for 7 days. In the next step, the samples were again scanned using the micro-CT method and analyzed in comparison with the previous graphs [Figures 2 and 3].

Micro-CT scans of all samples before and after the dissolution test were performed using the LOTUS-NDT micro-CT scanner (Matin Behin Negareh Imaging Technology Center, Tehran, Iran) with a voltage of 60 kV and a current of 60 mA without a filter. The total scanning time of each set of samples was approximately 2 h and the nominal resolution was set at 16 μm. The resulting images were evaluated using LOTUS NDT-REC and LOTUS NDT-3D software, Matin Behin Negareh Imaging Technology Center (Tehran-Iran).

To analyze the changes, first, the final images were superimposed on the initial images using MATLAB software. Matching parameters in this software included a relative algorithm to match the volume of two images regarding the position and orientation. The initial and final images were segmented by ImageJ/FIJI software,[17] and the upper and lower thresholds for the gray values were determined based on the lower value for dentine or glass and the maximum gray value for the filling material.

After setting the spatial resolution, the initial and final volumes of the canal filling materials were calculated using MATLAB software. The difference between the final and initial volume was obtained through the numerical difference between the final volume and the initial volume of the sections. This number presents changes in volume after the dissolution test.

Statistical analysis

Data were analyzed using SPSS software (IBM® SPSS® Statistics 21: Armonk, New York, United States). Descriptive data were presented as frequency, percentage, mean, and standard deviation. The Shapiro–Wilk and Kolmogorov–Smirnov tests were used to investigate the normality of the data. The Mann–

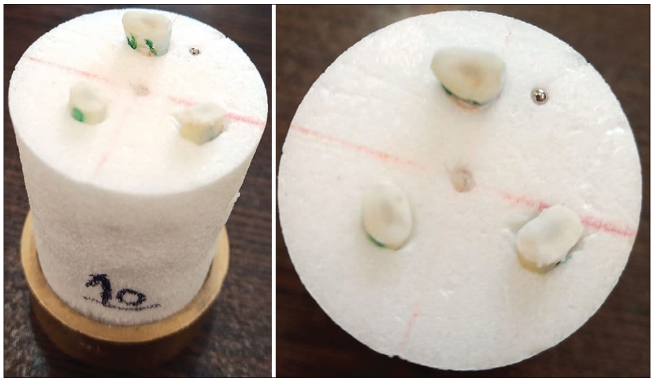

Figure 1: How the examined teeth enter the micro-computed tomography scanner.

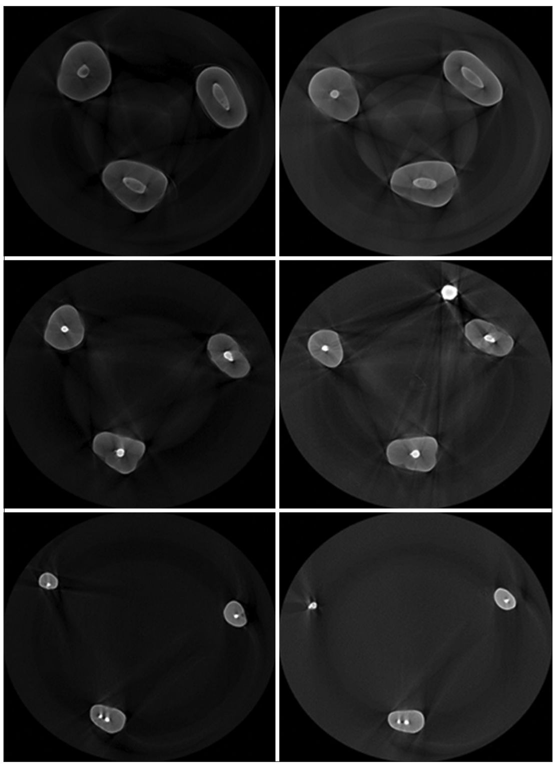

Figure 2: An example of the initial and final cuts from the selected coronal, middle, and apical sections resulting from micro-computed tomography (micro-CT) scanning of the mineral trioxide aggregate group (three samples entered into the device). The initial and final scans are not the same sections of the same tooth; therefore, they are comparable and are displayed only to present the type of images obtained from micro-CT scanning. The right column presents the initial images and the left column presents the final images.

Whitney test was used to compare the two groups, and the differences were ultimately not significant. The level of significance was set at 0.05 ($P < 0.05$).

The operators were not aware of the type of sealer used for each sample in any stage of scanning and software analysis.

RESULTS

In the MTA group, the average volume change was 0.4278 m^3 and the median was 0.2225 m^3. The minimum and maximum values were − 0.98 (negative means decrease in volume) and 1.95 m^3, respectively. In the AHP group, the average volume change and the median were 0.3638 mm^3 and − 0.2025, respectively, and the minimum and maximum values were − 1.55 and 2.26, respectively.

The two groups were not significantly different in terms of changes in volume ($P = 0.478$). The average percentage of volumetric dimensional changes was estimated at 9.85% and 5.34% in the EDS group and AHP group, respectively [Tables 1, 2 and Figures 1, 2, 4].

DISCUSSION

The results of the present study showed that the average dimensional changes of EDS (0.4278 mm^3) were not significantly different from AHP (0.3638 mm^3) and both groups showed a slight expansion. In 2020, Jo *et al*. compared three bioactive sealers EDS, Well-Root ST, and Nishika Canal Sealer BG with resin sealer AHP in terms of physical, chemical, and biological properties.

In this study, both EDS and AHP sealers showed a tendency to expand in Hank's solution. However, unlike AHP, a significant reduction in the dimensions of EDS was observed in distilled water.[18] In the present study, both the above-mentioned sealers showed positive volume changes (expansion) in the PBS solution, which confirms the results of the investigation of these two sealers in the HBSS solution.

Since the PBS and the HBSS solutions are much more ideal for estimating the body fluid environment compared to water,[19] it seems that the different results of EDS in distilled water are not very important.

In 2017, Lee *et al*. evaluated the flow, final setting time, radiopacity, dimensional stability, and pH changes in three bioceramic sealers (EndoSequence BC, EDS, and MTA Fillapex) and three epoxy resin-based sealers (AHP, AD Seal, and Radic-Sealer) and compared the changes using the ISO 6876/2012 and ANSI/ADA standards. Their results showed that the two sealers (EDS and AHP) similarly showed the least dimensional changes on different days after the

Table 1: Basic data related to the volume of two sealers (mm³)

Measures	Sealer type	Mean volume	SD	Median	Maximum	Minimum	Range
Initial volume	EndoSeal MTA	4.0629	1.93059	3.5195	9.47	2.04	7.43
	AHP	4.6892	2.27910	3.7735	9.79	2.48	7.32
Volume after intervention	EndoSeal MTA	4.4035	2.46299	3.6485	11.42	2.00	9.42
	AHP	5.0520	3.01792	4.8490	11.61	1.98	9.63

SD: Standard deviation; MTA: Mineral trioxide aggregate; AHP: AH Plus

Table 2: Volume changes (sealer volume difference before and after the intervention) in cubic millimeters in two groups

Sealer	Mean volume	SD	Median	Maximum	Minimum	Range
EndoSeal MTA	0.4278	0.85918	0.0225	1.95	−0.98	2.93
AHP	0.3638	1.17874	−0.2025	2.26	−1.55	3.81

SD: Standard deviation; MTA: Mineral trioxide aggregate; AHP: AH Plus

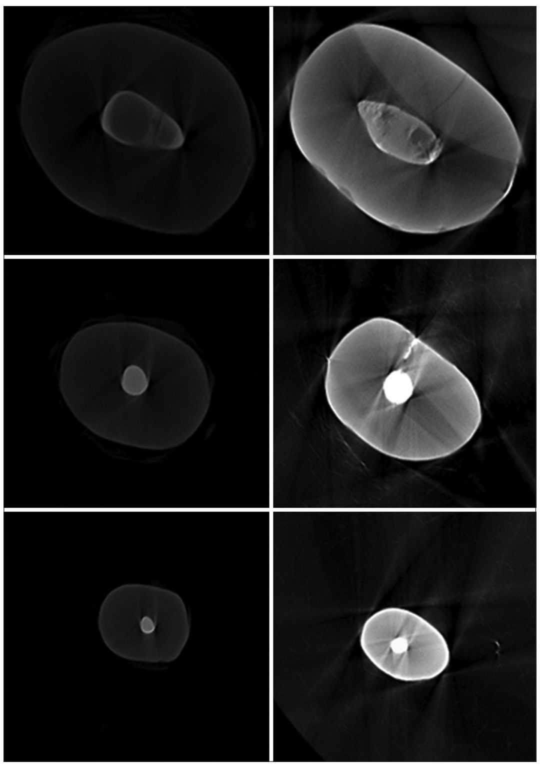

Figure 3: An example of the initial and final cuts from the selected coronal, middle, and apical sections obtained from microsite imaging of the AH Plus group (a single sample isolated from the three-piece stereotype). The initial and final images are not exactly from the same sections of the same tooth. Therefore, they are not comparable and are displayed only to present the type of images obtained from micro-computed tomography scanning. The right column presents the initial images and the left column presents the final images.

intervention,[20] which was consistent with the results of the present study.

In 2016, Silva *et al*. conducted a study to evaluate the solubility and dimensional changes of an MTA-based sealer named MTA Fillapex and compared it with the gold-standard sealer AHP with the micro-CT imaging approach. In this study, no obvious difference was observed in the amount of material lost in the two types of sealer after comparing the initial and final images in terms of dimensional changes and material displacement.[14]

However, according to the results of the above study, MTA Fillapex showed a greater rate of material exit from the end of the root, which represents its higher dimensional changes compared to AHP.[14] Changes in the volume of materials inside the canal, as one factor of dimensional stability in the above study, were not observed in any of the two sealers, which was in line with our results. On the other hand, the second factor of the mentioned study, namely, the exit of materials from the root canal, was not a variable in the present studies and therefore not evaluated.

It should be noted that the Fillapex MTA sealer has a different composition and characteristics from another sealer in this group, namely EDS. In this regard, one can refer to the predominance of the resin base and the late setting of MTA Fillapex compared to EDS.[21] Therefore, the discrepancies between the results of this study and those obtained in other studies can be explained by different interpretations of the dimensional changes and a difference in the type of MTA-based sealer used in this study.

In 2019, Torres *et al*. studied the dimensional stability and changes in the volume of AHP, MTA Fillapex, and Endofill sealers using conventional dimensional stability (ISO) and microsite tests. The most and the least dimensional and volume changes were observed for MTA Fillapex and AHP, respectively.[3] However, similar to the previous study, this study investigated another type of MTA-based sealer as well, and

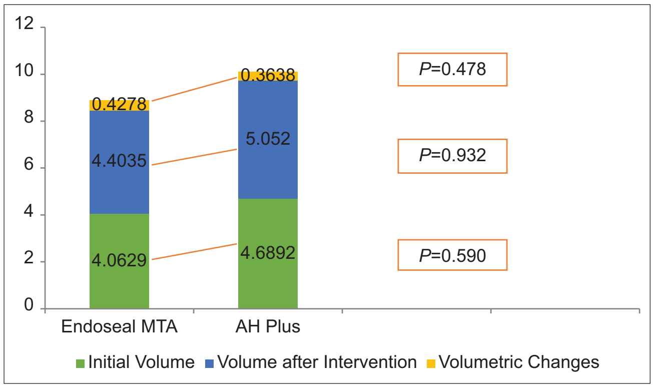

Figure 4: Comparing data in the two groups.

obviously, some differences might exist regarding the physical properties of these two types of sealer.

Moreover, in the current study, the average percentage of volume dimensional changes in the EDS group and the AHP group was 9.85% and 5.34%, respectively. In the above study, MTA Fillapex showed the highest contraction (0.56%) and AHP showed the highest expansion (−1.69%). It was found that the level of expansion of AHP and contraction of MTA Fillapex was outside the ISO standard range, while Endofill met the desired level (−0.76%).

The percentages of volume changes in the above study were measured as percentages of linear dimensional changes with a different method. Therefore, the difference in the percentage of dimensional changes in the AHP sealer group is logical. The results of these studies, in line with the results of the present study, showed the appropriate dimensional stability and reliability of EDS filling.

On the other hand, the sealing effect of MTA sealers was reported to be significantly lower than AH-26 in a study that investigated and compared the sealing effect of some MTA-based sealers, including EDS, with a resin sealer (AH 26) using the color penetration method.[22]

It seems that these results were not aligned with the findings of the current study, since in the present study, there was no significant difference between the dimensional changes of EDS and AHP sealers. Therefore, it is likely that there is no significant difference between the sealing effect. However, these discrepancies can be due to the application of different approaches in studies on dimensional changes and the sealing effect.

AHP sealer is known as a sealer with the lowest dissolution rate among common sealers.[23-26] When mixing this sealer, the diepoxide compound and the paste containing polyamine are mixed, and each amine group reacts with an epoxy group to form a covalent bond. The resulting polymer consists of a network of links with high cross-links, which makes it very strong and stable.[27]

This phenomenon justifies the low dissolution and high dimensional stability of this sealer.[25,26] On the other hand, in many studies, including the present study, generally, some expansion during setting is observed in resin sealers. This phenomenon is justified based on the inherent water absorption after setting resin-based sealers containing hydrophilic monomers.[26,28]

On the other hand, calcium silicate-based sealers have the ability to interact with dentin, which causes calcium and silicon connections within tubules.[29] Apatite nucleation at the dentin–sealer interface may increase the sealing ability of these sealers by reducing bubbles at the interface and improving resistance to material displacement.[30]

However, in laboratory studies conforming to the ISO, the dissolution rate and dimensional changes of one of the widely used calcium silicate-based sealers, namely, MTA Fillapex, were reported to be less significant compared to resin sealers, like AHP. However, these results were challenged by similar studies under conditions similar to those in the clinic and with new methods (micro-CT).[14] On the other hand, these poor results might be explained by the unbalanced ratio of resin/MTA in this sealer.

The unbalanced ratio of resin/MTA may explain the unfavorable properties, such as long working time and setting time, excessive flowability, and solubility reported in previous studies.[31-34] However, the sealer studied in this study is at the opposite end of another sealer in this group, and studies have reported a high setting speed for it.

The setting mechanisms of EDS include not only the hydration reaction of calcium silicate but also the pozzolanic reaction (transformation of calcium hydroxide into insoluble phases like calcium silicate hydrate),[35] which allows for rapid setting of this sealer.[36]

Therefore, the use of EDS is highly recommended in studies, especially in treating root canals that are difficult to fill with resin sealers, such as teeth with an open apex or root perforations.[37]

Regarding the limitations of the study, the approximate time interval of taking micro-CT images from the canal filling time can be considered a confounding factor in the study results. Furthermore, to reduce the costs, each time, the three samples were scanned simultaneously, which caused a relative decrease in the quality of imaging. Anyway, the overall results of the study provide insight into the differences between these two sealers.

CONCLUSION

It seems that EDS A can be considered a reliable sealer in endodontic treatments and be subjected to further investigation due to its cost, ease of use by the dentist, and commercial availability in addition to its favorable characteristics, like small dimensional changes.

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Conflicts of interest

Behin Negareh Co., Ltd., Tehran, Iran, cooperated with the project through advanced sample preparation and providing a micro-CT imaging device.

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