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Analysis of porosity, sealer dissolution and apical extrusion of endodontic sealers: A micro computed tomography study

Neha Jasrasaria, Aseem P. Tikku, Ramesh Bharti *

Department of Conservative Dentistry and Endodontics, King George Medical University, Lucknow, India

A R T I C L E I N F O

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A B S T R A C T

Aim: The aim of the study was to determine the porosity, dissolution and apical extrusion of AH Plus, MTA Fillapex and EndoSequence BC sealer after immersion in phosphate buffered saline (PBS) using microcomputed tomography (micro-CT).

Methodology: Forty-eight single-rooted teeth were selected. Gutta percha and one of the aforementioned root canal sealers was used for obturation using continuous wave technique. The specimens were scanned after obturation and after seven days of immersion in PBS, by using micro–computed tomography. Porosity, sealer dissolution and apical extrusion were calculated. Statistical analysis was done by using paired *t*-test, post hoc tukey test and Fischer exact test.

Results: Significantly higher percentage of porosity and dissolution of sealer in the apical 4 mm was found for MTA Fillapex and EndoSequence BC sealer than for AH Plus. The incidence of apical extrusion was significantly more in MTA Fillapex (56.25%), followed by EndoSequence BC (31.25%) and AH Plus (0%).

Conclusions: None of the three root canal sealers exhibited perfect three-dimensional obturation. The sealers manifested porosity, dissolution and apical extrusion to varying degrees both after obturation and after storage in PBS for 7 days.

1. Introduction

One of the fundamental hurdles of endodontic treatment has been the adequate filling of root canals, ensuring a long-term successful prognosis of the tooth. Three-dimensional obturation prevents the ingress of microorganisms and infiltration of periapical fluids. It also entombs any surviving microorganisms.[1] Gutta percha has been used as a core obturation material for decades. One of its significant pitfalls has been its lack of bonding to the root canal walls, which leads to an adverse gap formation. Root canal sealers were hence formulated to enhance the adhesion at the gutta percha-root canal wall junction.

AH Plus (Dentsply, DeTrey, Konstanz, Germany) is a root canal sealer based on epoxy resin. It exhibits desirable properties, such as biocompatibility, short setting time, low dimensional change, and low dissolution. AH Plus is hence reckoned as the “gold standard” amongst the various root canal sealers.[2] MTA Fillapex (Angelus, Londrina, PR, Brazil) is the first commercially available sealer based on calcium silicate. Studies show that MTA Fillapex manifests exorbitant dissolution and dimensional fluctuations.[3] EndoSequence BC sealer (Brassler, Savannah, GA) is a premixed sealer available in injectable form. Its setting reaction utilizes moisture from the dentinal tubules.[4] EndoSequence BC Sealer demonstrates excellent physical properties and biocompatibility.

Voids at the gutta percha dentin interface may lead to microleakage and serve as a hotbed for microorganisms, leading to endodontic treatment failure. Furthermore, the concentration of stresses in the area of porosity may adversely affect the physical and mechanical behaviour of the root canal sealer.[5] Dissolution and apical extrusion of the root canal sealer, in addition to the formation of voids, may also liberate compounds that could trigger host immune response. According to the specifications cited by the American Dental Association (ADA, 2000)[6] and International Organization for Standardization (ISO, 2002)[7] solubility of root canal sealers should be less than 3%.

Microcomputed tomography (micro-CT) is characterized by its non-destructive nature. Micro- CT is used for quantitative and qualitative analysis of porosity, volume, and dimensional changes after obturation, which may not be achieved with other methods.[8,9] Conventional tests pose a variety of limitations, and there also is a paucity of information regarding the association between the physical properties of endodontic

* Corresponding author.
E-mail addresses: nehajas001@gmail.com (N. Jasrasaria), crown_tikku@yahoo.com (A.P. Tikku), rameshbharti@kgmcindia.edu (R. Bharti).

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sealers and the methodologies to assess these properties. Hence, this study aimed to investigate the porosity, dissolution, and apical extrusion of AH Plus, MTA Fillapex, and Endosequence BC sealers by using micro-CT analysis after storage in a simulated body fluid.

2. Materials and method

Prior to the study, approval was obtained from the institutional Ethical Committee (97th ECM II B-Thesis/P153).

2.1. Selection of samples

Forty-eight freshly extracted single, straight-rooted anterior human teeth with fully formed apices were collected. After extraction, each specimen was cleaned of any debris on the external root surface. 0.1% thymol solution at 5 °C was employed to store the specimens.

2.2. Root canal preparation of specimens

The specimens were decoronated to obtain a standard length of 16 mm. Access cavity preparation was done on all specimens using a high-speed handpiece. Apical patency was established with a No. 10 K-file. The working length was kept 1 mm short of this measurement.

The specimens were sequentially instrumented using ProTaper Gold (Dentsply Maillefer, Ballaigues, Switzerland) rotary files up to F3 (size 30, 0.09 taper). The specimens were irrigated using a 30- gauge, side vented needle, 20 mL 5.25% sodium hypochlorite (NaOCl) solution per tooth, and 3 mL of 17% EDTA for 3 min irrigation. This was followed by irrigation with distilled water.

2.3. Experimental groups

The specimens were then randomly divided into three groups depending on the root canal sealer to be used.

Group 1: AH Plus (Control)
Group 2: MTA Fillapex in 2 paste form **(Experimental group)**
Group 3: Endosequence BC (Experimental group)

Each of the three groups was obturated using the same technique, process, and standard instruments. At the previously established working length, a size 30/0.09 tapered gutta percha was fitted in the root canal. The root canal sealer was mixed, and the root canal was coated with the sealer using a lentulo spiral. The BeeFill 2 in 1 device (VDW, Munich, Germany) was used for obturation using the continuous wave technique. Intraoral periapical radiographs were obtained to determine the adequacy of the root canal obturation. Glass Ionomer Cement (GC Corporation, Japan) was used to seal the access cavities.

2.4. Micro-CT acquisition and reconstruction

The specimens were individually subjected to scans after obturation (initial stack) and after immersion in Phosphate Buffered saline (PBS) for seven days (final stacks). Scanning was done using Quantum FX micro-computed tomography imaging system (PerkinElmer Inc., Massachusetts, United States). The acquisition parameters were as follows: 90 kV, 160 μA, field of view 60 mm, scanning time 4.5 min, 0.5° rotation step through 360°. A series of 512 images were obtained per specimen in the form of DICOM (Digital Imaging and Communications in Medicine). The files were then reconstructed and viewed using ImageJ v1.53 (64-bit) software, Dolphin Imaging v11.9.07.24 software, and Amira v2020.2 software.

3. 3D Image analysis

Porosity: A 2D porosity analysis was performed on Image J software, where initial stack and final stack co-aligning of the images were done, and voids, if any, were identified (Fig. 1). The 3D reconstructed images were visualized using Amira software (Fig. 2). The region of interest was the root canal space. Differentiation of the root dentin from gutta percha, sealer, and voids was done by setting a segmentation threshold.

The porosity of the sealers was measured as the percentage of voids throughout the extent of the obturation.

The percentage of voids was determined as follows:

$$\textbf{Voids}(\%) = \frac{\textit{volume of the voids}}{\textit{volume of the filling material}}\ \textbf{X100}$$

Dissolution: The apical 4 mm of the root canal obturation was chosen as the region of interest. The volume of the obturation at the apical 4 mm of the initial stack (vol1) and the final stack (vol 2) was recorded in the apical 4 mm using Dolphin Imaging software.

$$\%\ \textbf{Sealer dissolution} = \frac{(\textit{vol}\mathbf{1} - \textit{vol}\mathbf{2})}{\textit{vol}\mathbf{1}}\ \textbf{X 100}$$

Apical Extrusion: This was an observational parameter. The two reconstructed datasets (the final stack and the initial stack) were co-aligned using ImageJ software. The apical limit of the filling material was kept 1 mm short of the apex. Any extrusion of the obturation material beyond the apical limit was used to represent the apical extrusion of sealers (Fig. 3).

3.1. Statistical analysis

SPSS version 21.0 software was used for the statistical analysis. The values were presented as mean ± SD and n (%). One way analysis of variance (ANOVA), Tukey's post hoc test, *t*-test, and Fisher's exact test were used to analyze the results and make comparisons among the various groups.

ANOVA was used to compare the mean % porosity after obturation and mean volume loss after obturation in the three groups. Tukey's post hoc test was used to perform pairwise comparison in above groups. T-test was used to compare the % porosity values after obturation and after seven days of obturation in each of the three groups. Fisher's exact test was used to assess the association between categorical variables, i. e. the association between the type of root canal sealer used and the proportion of teeth that showed apical extrusion.

4. Results

The percentage porosity in all groups after obturation and after seven days of storage in PBS, is represented in Table 1. The percentage porosity was highest for MTA Fillapex after obturation and after seven days of storage in PBS. There was no significant difference in percentage porosity after obturation and percentage porosity after seven days for AH Plus ($P = 0.52$), MTA Fillapex ($P = 0.94$), and Endosequence BC sealer ($P = 0.12$). The percentage of sealer dissolution in all the groups is represented in Table 2.

The analysis of apical extrusion was an observational parameter. The incidence of apical extrusion was highest in MTA Fillapex (56.25%) followed by EndoSequence BC (31.25%). None of the samples in AH Plus showed apical extrusion (0%). The pairwise comparison revealed apical extrusion incidence in the MTA Fillapex group was significant ($P = 0.0008$). Whereas the AH Plus group showed results that were not significant ($P = 0.2852$), as shown in Table 3.

5. Discussion

Endodontic root canal sealers should ideally exhibit a 3D hermetic seal with no pores, low dissolution, and low dimensional changes, amongst other desirable properties. At present, none of the endodontic sealers is adjudged to be ideal.

Previous studies have used several conventional methods to assess

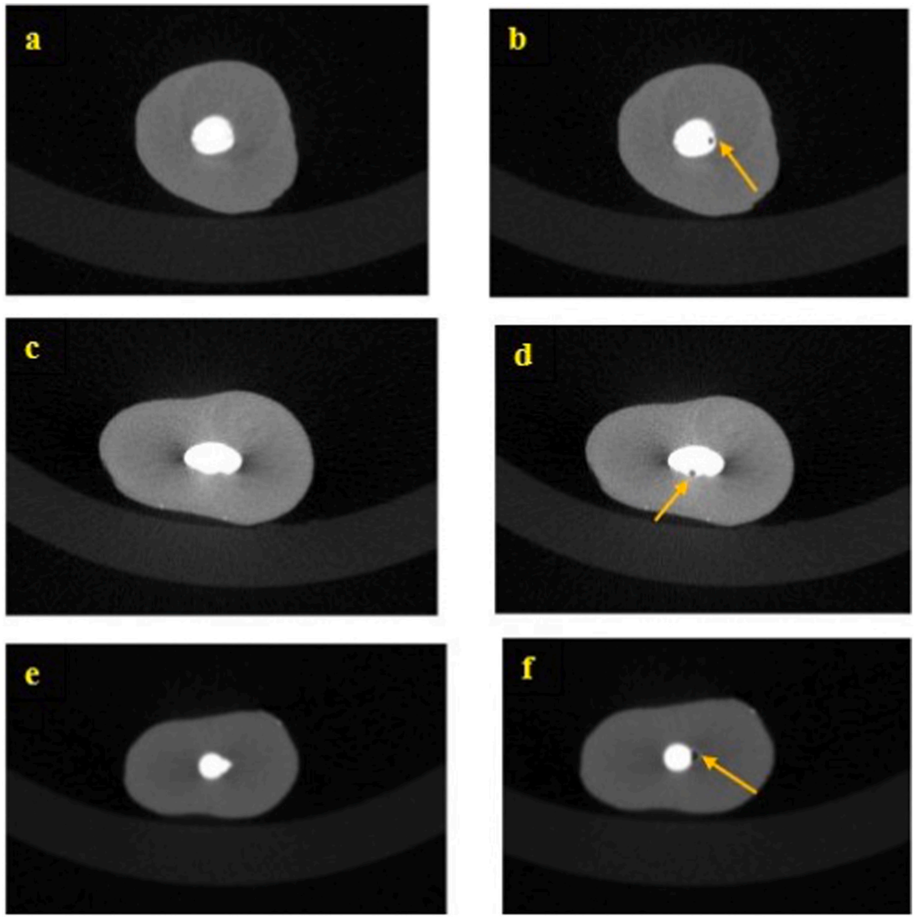

Fig. 1. Specimens seen directly after obturation using ImageJ software a) AH Plus c) MTA Fillapex e) Endosequence BC sealer.

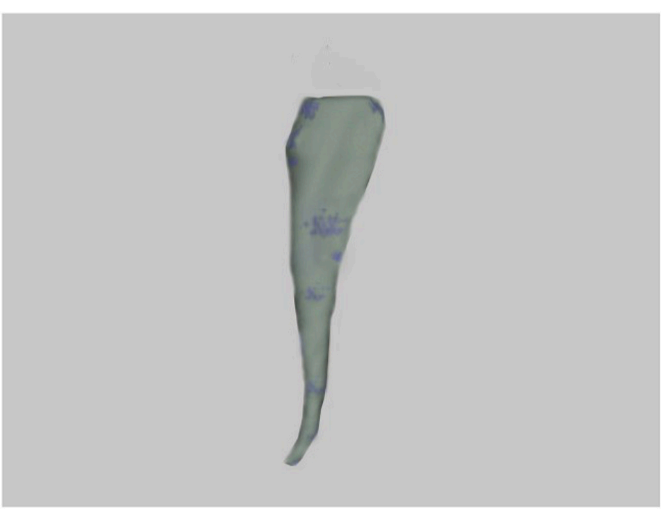

Fig. 2. 3D reconstruction of root canal filling material showing the porosity indicated by blue colour.

porosity in root canal filling materials. Inconsistency and time intensiveness have been the pitfalls of these methods.[10] Micro-CT has been implemented to investigate of the presence of porosity because of its high precision and spatial resolution, along with its non-destructive characteristic. Gutta-percha, sealer, and tooth exhibit different greyscale values, which allow for their distinction.[8]

Micro-CT provides qualitative and quantitative tridimensional analysis that has been used to appraise the volumetric difference and dimensional behavior of root canal filling materials.

MTA Fillapex and EndoSequence BC were chosen for this study because they have been reported to combine with the phosphate in dentinal fluids, resulting in a structure that is crystalline in nature and resembles the tooth and bone apatite architecture, thereby enhancing sealer-dentin adherence.[4] Although both EndoSequence BC sealer and MTA Fillapex are bioceramic sealers, they differ in composition. MTA Fillapex is a hybrid root canal sealer with salicylate resin and an MTA component, whereas Endosequence BC sealer is a true bioceramic sealer based on calcium silicate.

The samples were submerged in Phosphate Buffered Saline (PBS) because it mimics the ion concentration, osmolarity, and pH of human body fluids. Being isotonic to human tissue fluids, it closely simulates the in vivo clinical situation.[11] Human anterior teeth were used as the canal volume of these teeth is large. This allows for easy quantification of voids and sealer volume loss. The crowns were decoronated to provide an equalized length of the tooth, hence providing a standardized quantification.

To minimize bias, the root canals were prepared up to F3 ProTaper Gold to keep a similar apical diameter in all three groups. Continuous wave obturation technique was used for obturation as it has been reported to have superior proximity to the root canal dentin and fewer voids in contrast to other obturation techniques.

In the current investigation, the volume of porosity in the root canal filling after obturation and after seven days of immersion in PBS was maximum for MTA Fillapex, followed by EndoSequence BC sealer, and minimum for AH Plus. Milanovic et al. have demonstrated that MTA Fillapex exhibits higher porosity than AH Plus sealer. According to the authors, porosity between 3% and 6% does not show clinical relevance.

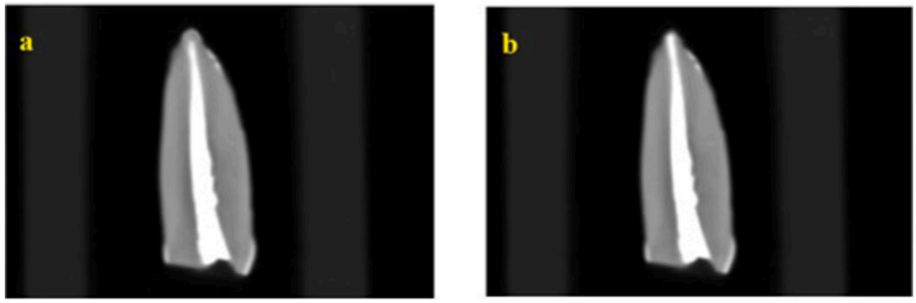

Fig. 3. Images depicting a) Root canal filling after obturation b) Extrusion of filling material beyond the apical limit of obturation observed after seven days of immersion.

Table 1
Comparison of percentage porosity after obturation and after seven days in three groups.

N = 16 Groups	% Porosity after obturation Mean ± SD	% Porosity after seven days Mean ± SD	't'	'P'
AH Plus	2.062 ± 0.5111	2.1852 ± 0.5627	0.65	0.52
MTA Fillapex	4.4900 ± 0.8018	4.5100 ± 0.6229	0.08	0.94
Endosequence BC	2.7206 ± 0.4981	3.0356 ± 0.6136	1.59	0.12

Table 2
Percentage dissolution after obturation and after seven days in three groups.

Groups	Volume after obturation mean ± SD (in mm^3)	Volume after seven days mean ± SD (in mm^3)	Percentage volume loss mean ± SD
AH Plus	6.4712 ± 2.0309	6.4094 ± 2.0121	0.9144 ± 0.1875
MTA Fillapex	6.3813 ± 1.9322	6.2156 ± 1.8863	2.5938 ± 0.6839
EndoSequence BC	6.7526 ± 1.1632	6.6225 ± 1.1329	1.9576 ± 0.7139

Table 3
Comparison of apical extrusion incidence in three groups by Fisher Exact Test.

Comparison	'P'	Significance
AH Plus VS MTA Fillapex	P = 0.0008	Significant
AH Plus VS EndoSequence BC	P = 0.0434	Significant
MTA Fillapex VS EndoSequence BC	P = 0.2852	Not Significant

This finding was attributed to bismuth oxide, used as a radiopacifier in the sealer.[5]

Initial volumetric shrinkage of salicylate in MTA Fillapex contributes to the increased porosity. On the contrary, during the setting reaction, epoxy resin sealers have displayed some degree of expansion.[3,12,13] AH Plus shows close adaptation to the dentin by forming covalent bonds between the collagen of the root dentin and the epoxy resin.[14,15]

Contradictory results were reported in a study by Huang et al. where micro-CT and nano-CT analysis revealed higher porosity in AH Plus.[16] The particle size and alkaline nature (about 2 μm in diameter) of the EndoSequence BC sealer facilitate the infiltration of the sealer into the dentinal tubules. AH Plus is acidic, which limits its bonding to dentin. It also exhibits polymerization contraction. These were considered the reasons behind the superior sealing ability of EndoSequence BC sealer.[17]

In the current research, the percentage of sealer dissolution was maximum for MTA Fillapex sealer, which was supported by studies done by Urban et al.[18] Borges et al.,[19] Torres et al.,[12] Amoroso- Silva et al.[3] the salicylate resin in MTA Fillapex was inextricably linked with the high dissolution and volumetric loss of this material.[20] AH Plus contains an amine group that combines with an epoxide group, forming a highly cross-linked polymer, explaining the low solubility.[19] Endosequence BC sealer showed higher dissolution, attributed to calcium phosphate silicate, which could lead to increased solubility. Polymeric chains are distant and porous in AH Plus, which may lead to higher water sorption.[21,22]

In the present study, the incidence of apical extrusion was significantly higher in the MTA Fillapex group than in the Endosequence BC group and AH Plus group. This result agrees with studies by Chybowski et al.,[23] and Fonseca et al.,[24] who observed that teeth obturated using Endosequence BC sealer typically exhibit higher sealer extrusion because of its superior flow. Additionally, using an applicator syringe to place bioceramic sealers into the canals may be partly responsible for the increase in their apical extrusion.[15]

Silva et al.,[25] in their study, observed a significant difference between the extrusion of AH Plus and MTA Fillapex. No evidence of material extrusion was found in the AH Plus filled samples, whereas MTA Fillapex was found to be extruded through the apex in all but one sample. No significant reviews were available against the results of this study.

Even though care was taken to simulate in vivo conditions, further research is needed at the clinical level. Also, the present study used single-rooted anterior teeth; however, these sealers must be tested in other teeth as well. And micro-computed tomography can only be used for scanning specimens in vitro because of the risk of high radiation exposure[26]; therefore, its application is limited to laboratory studies only.

6. Conclusion

Within the limitations of the study, none of the three root canal sealers used in the study evaluated exhibited perfect three-dimensional obturation. All root canal sealers resulted in varying degrees of porosity, dissolution, and apical extrusion immediately after obturation and after seven days of immersion in PBS solution using this novel methodological approach. A significantly higher percentage of porosity and dissolution of sealer in the apical 4 mm was found for MTA Fillapex and EndoSequence BC sealers than for AH Plus. The incidence of apical extrusion was significantly higher in MTA Fillapex, followed by EndoSequence BC and AH Plus. However, studies involving a larger sample size are needed for more confirmatory results.

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