

Comparative evaluation of dentinal tubule penetration and adaptation of epoxy resin-based, bioceramic-based and bioactive glass-based root canal sealers using SEM: An in vitro study.

¹Dr. Lija Tharakan James, Post Graduate student, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

²Dr. Agrawal Muskan, Post Graduate student, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

³Dr. Sandhiya Rajendran, Post Graduate student, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

⁴Dr. Neerja Kunhappan, Lecturer, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

⁵Dr. Anita Chandrawanshi, Lecturer Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

⁶Dr. Chitra Raghavan, Lecturer Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

⁷Dr. Sanjeev Kunhappan, MDS, Professor, Department of Conservative Dentistry and Endodontics, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

Corresponding Author: Dr. Sanjeev Kunhappan, MDS, Professor, Department of Conservative Dentistry and Endodontics, Govt. Dental College, Raipur, Chhattisgarh, Pin: 492001.

Citation of this Article: Dr. Lija Tharakan James, Dr. Agrawal Muskan, Dr. Sandhiya Rajendran, Dr. Neerja Kunhappan, Dr. Anita Chandrawanshi, Dr. Chitra Raghavan, Dr. Sanjeev Kunhappan, “Comparative evaluation of dentinal tubule penetration and adaptation of epoxy resin-based, bioceramic-based and bioactive glass-based root canal sealers using SEM: An in vitro study”, IJDSIR – June – 2026, Volume – 9, Issue – 3, P. No. 01 – 11.

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Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Background: Root canal sealers play a decisive role in endodontic treatment success through their potential to enter dentinal tubules and effectively adapt to root canal dentin.

Aim: This investigation aims at comparatively analysing penetration in dentinal tubule and adaptation of epoxy resin-based (AH Plus), bioceramic-based (CeraSeal) and bioactive glass-based (NISHIKA CANAL SEALER) endodontic sealers utilising Scanning Electron Microscope (SEM).

Materials and Method: Ninety single-rooted mandibular premolars having a single canal were standardised to 14 mm length, instrumented with ProTaper universal rotary files and allocated randomly among three categories (n = 30) according to the sealer used: Group I (Epoxy resin-based), Group II (Bioceramic-based) and Group III (Bioactive glass-based). Following obturation using cold lateral condensation, samples were split vertically and evaluated under SEM for dentinal tubule penetration and marginal gap at sealer-dentin interface.

Statistical analysis: One-way ANOVA and Tukey's Post Hoc test were applied to statistically analyse the data.

Results: Group II (Bioceramic-based) showed significantly higher dentinal tubule penetration and the least marginal gaps ($p < 0.001$), succeeded by Group III (bioactive glass-based), while Group I (epoxy resin-based) showed significantly greater gaps and lower penetration compared to Group II (bioceramic-based). The coronal level demonstrated maximum dentinal tubule penetration and minimal marginal gaps across all sealers.

Conclusion: Bioceramic-based sealer (CeraSeal) showed superior dentinal tubule penetration and interfacial adaptation compared to the epoxy resin-based (AH Plus) and bioactive glass-based sealers (Nishika Canal Sealer).

Keywords: Bioactive Glass-Based, Bioceramic-Based, Dentinal Tubule Penetration, Epoxy Resin-Based, Marginal Adaptation, SEM.

Introduction

Effective endodontic therapy requires elimination of infected pulpal and peri-radicular tissues, prevention of bacterial reinfection and the creation of a three-dimensional, hermetically sealed obturation.¹ Microorganisms and their by-products are the primary etiological factors in pulpal and periapical diseases.² Hence, endodontic therapy focuses on comprehensive debridement, proper shaping and complete sealing, particularly in the apical region of root, to ensure periapical healing.³

Inadequate root canal sealing has been identified as a significant contributor of failed endodontic treatment (60 %), highlighting the need for obturating materials capable of achieving a durable hermetic seal.⁴ Although gutta-percha remains the gold standard obturating material due to its biocompatibility and dimensional stability, its limited flow into canal irregularities and

tubules of dentin necessitates the use of a root canal sealer.⁵ By sealing dentinal tubules, ramifications and anatomical imperfections, endodontic sealers improve adaptation at the dentin-obturating material interface and help seal the canal system.⁶

Dentinal tubule penetration of sealers is crucial, as deeper penetration enhances mechanical interlocking, retention and reduces microleakage by entombing residual bacteria.⁷ Studies by Sen et al. and Balguerie et al. have shown an inverse relationship between sealer penetration and microleakage.^{8,9} Sealer penetration is affected by sealer properties such as viscosity, surface tension and wettability, as well as dentinal tubule anatomy.⁸ Adaptation of sealer is another important factor influenced by dentin surface characteristics, sealer properties and clinical technique. Optimal adhesion depends on a clean dentin surface with favorable surface energy, while the wettability and surface tension of sealer determine its ability to spread uniformly and adapt to canal wall irregularities.⁶

Various root canal sealers have been developed, including epoxy resin, bioceramic and bioactive glass-based sealers. Despite their hydrophobic nature, which may limit penetration in moist environments, epoxy resin-based sealers especially AH Plus are often used due to their superior sealing efficiency and low solubility. Bioceramic-based sealers, including premixed formulations like CeraSeal (Meta Biomed Co., Korea), have gained popularity because of their bioactivity, hydrophilicity and ability to form hydroxyapatite at the sealer-dentin interface. Bioactive glass-based sealers such as Nishika Canal Sealer (Nippon Shikan Yakuhin, Japan), exhibit ion release and potential regenerative properties; however, limited data are available regarding their sealing performance.

Considering the critical role of dentinal tubule penetration and marginal adaptation in obturation success and the paucity of evidence on bioactive glass-based sealers, intention of our study was to comparatively assess the penetration in dentinal tubule and marginal adaptation of an epoxy resin-based (AH Plus), a bioceramic-based (CeraSeal) and a bioactive glass-based (Nishika Canal Sealer) sealer.

Materials and Method

Ninety freshly extracted human permanent mandibular premolars were obtained from the Department of Oral and Maxillofacial Surgery at Government Dental College, Raipur, Chhattisgarh, which were advised for extraction due to periodontal or orthodontic reasons. Using an ultrasonic scaler, tissue remnants were eliminated from teeth, disinfected in 10% formalin and stored in distilled water containing 0.1% thymol until use.¹⁰

Radiovisiographic examination was performed to ascertain a single canal configuration and to assess root curvature using Schneider's method.¹¹ Teeth with curvatures between 0° and 20° were selected and sectioned with a diamond disc to a length of 14 mm. The external root surfaces were covered in a thin aluminium foil layer and embedded in self-cure clear acrylic resin block to facilitate handling during instrumentation.

A size 10 K-file was used to verify canal patency and a glide path was prepared up to the working length using a size 15 K-file. The crown-down method of biomechanical preparation was carried out at 250 rpm using ProTaper Universal rotary instruments (S1, Sx, S2, F1, F2, F3). 3% sodium hypochlorite was used for irrigation during instrumentation, followed by 17% EDTA for one minute and distilled water final rinse. Sterile ProTaper F3 paper points were used for drying the root canal.

Three groups (n = 30) were randomly assigned depending on the sealer employed.

- **Group I (Epoxy resin-based sealer):** AH Plus sealer (Dentsply DeTrey, Germany).
- **Group II (Bioceramic-based sealer):** CeraSeal (Meta Biomed Co., Korea).
- **Group III (Bioactive glass-based sealer):** Nishika Canal Sealer (Nippon Shikan Yakuhin, Japan).

All sealers were manipulated according to manufacturer instruction and were placed in the root canals using a size 25 Lentulo spiral at slow speed, 2 mm short of the working length. Cold lateral condensation of ProTaper F3 gutta-percha cones was employed for canal obturation. Excess gutta-percha from coronal part of the samples were removed and were sealed with glass ionomer cement. To enable proper sealer setting, all samples were kept at thirty-seven degrees and a hundred percent humidity for 48 hours.

Following storage, all samples were retrieved from the acrylic resin blocks. Vertical grooves were placed in dentin along entire length on buccal and lingual surfaces using slow speed diamond disc. Samples were then split along the long axis using orthodontic wire cutter. One half of each sample was selected for analysis. The samples were cleaned of debris using solution of 15% Ethylene Diamine Tetra Acetic acid followed by 3% sodium hypochlorite for 2 minutes and were dehydrated by placing samples in a desiccator for 4 hours.⁹

After gold sputtering of samples mounted on metallic stubs, scanning electron microscopic evaluation was performed at coronal (9 mm), middle (6 mm) and apical (3 mm) levels to determine sealer penetration in dentinal tubule (500 X) (Figure 1) and marginal gaps along the sealer-dentin interface (1500 X) (Figure 2). Measurements were recorded at three points per level and

the mean values calculated at all levels were subjected to statistical analysis.

Statistical Analysis

Quantitative variables were described using mean, standard deviation and standard error. One-way analysis of variance (Welch's test) and the Tukey post hoc test were used to statistically assess the data. Using SPSS 11.5 for Windows (SPSS Inc., Chicago, IL, USA), analyses were conducted at the 5% significant level.

Results

Dentinal tubule penetration: Group II (Bioceramic-based) demonstrated the highest mean dentinal tubule penetration at all three levels, followed by Group I (Epoxy resin-based) and Group III (Bioactive glass-based) (Table 1, Graph 1). Sealer penetration was highest in the coronal and least in the apical level for all the three groups.

Intergroup comparison showed statistically significant differences between Groups I (Epoxy resin-based) and Group II (Bioceramic-based) and between Group II (Bioceramic-based) and Group III (Bioactive glass-based) ($p < 0.001$), while no significant difference was seen between Group I (Epoxy resin-based) and Group III (Bioactive glass-based) (Table 2).

Marginal gap at the dentin-sealer interface: Group II (Bioceramic-based) demonstrated the least marginal gaps at the dentin-sealer interface at all three levels, whereas Group I (Epoxy resin-based) showed the largest gaps, succeeded by Group III (Bioactive glass-based) (Table 1, Graph 2). Marginal gaps were least in the coronal and highest in apical level for all the three groups.

Intergroup comparison showed significant differences between Group I (Epoxy resin-based) and Group II (Bioceramic-based) and also between Group I (Epoxy resin-based) and Group III (Bioactive glass-based) ($p < 0.001$), while no significant difference was seen

between Group II (Bioceramic-based) and Group III (Bioactive glass-based) (Table 2).

Discussion

Root canal sealers enhance obturation by penetrating dentinal tubules, thereby improving retention, adaptation and entombing residual microorganisms to prevent reinfection. Ideal sealers exhibit low surface tension and good wettability to facilitate penetration into canal irregularities and achieve a hermetic seal.¹² In the context of increasing interest in newer root canal sealers, evaluating dentinal tubule penetration and sealer-dentin adaptation becomes particularly relevant, as these properties directly influence the long-term stability and sealing efficacy of root canal obturation.

In this investigation, the highest dentinal tubule penetration was shown by Group II (Bioceramic-based) at all three levels, succeeded by Group I (Epoxy resin-based) and Group III (Bioactive glass-based). The penetration of epoxy resin-based sealer (AH Plus) was moderate, significantly lower than bioceramic-based sealer (CeraSeal) and slightly higher than bioactive glass-based sealer (NISHIKA CANAL SEALER) with no significant difference.

Bioceramic-based sealer (CeraSeal) exhibited superior penetration owing to its flowability and very small particle size, averaging 0.2 μm and have hydrophilic properties as well as a low contact angle. The alkaline pH of calcium silicate hydration products may facilitate partial degradation of interfacial dentin collagen, enhancing tubule penetration.¹³ Additionally, moisture within dentinal tubules appears sufficient to initiate setting and lateral expansion of CeraSeal, even after canal drying, thereby improving penetration.¹⁴ These results are consistent with studies by Caceres et al. and El Hachem et al. reporting enhanced penetration of premixed bioceramic sealers.^{15,16}

Epoxy resin-based sealer (AH Plus) exhibited moderate penetration, likely influenced by its hydrophobic nature and dependence on optimal canal dryness, as well as factors such as presence of silicone oils, pseudoplastic viscosity and higher surface tension limiting uniform spread.^{17,18,19} Slightly greater penetration of epoxy resin-based sealer (AH Plus) compared to bioactive glass-based sealer (NISHIKA CANAL SEALER) may be due to low solubility and prolonged setting time (24 hours) favouring capillary flow.²⁰

In contrast, the shorter working (15 minutes) and shorter setting time (1 hour) of bioactive glass-based sealer (Nishika Canal Sealer) along with manual mixing variability, increased viscosity and rapid bioactive glass reactions, might have restricted its dentinal tubule penetration.²¹ However, these findings differ from those of Chew et al., who reported superior penetration with NISHIKA CANAL SEALER, attributing this to its ability to form hydroxyapatite like crystals inside dentinal tubules.²²

In the present study, the lowest marginal gap at sealer-dentin interface was shown by Group II (Bioceramic-based) at all three levels, followed by Group III (Bioactive glass-based) with no significant difference between them, while Group I (Epoxy resin-based) showed significantly highest gap formation. The least gaps observed with bioceramic-based sealers may be related to its slight setting expansion of 0.20% and biomineralization, leading to hydroxyapatite formation and improved sealer-dentin adaptation.¹⁹

Bioactive glass-based sealer (Nishika Canal Sealer) also showed good adaptation, likely due to hydroxyapatite-like crystal formation at the dentin-sealer interface through release of soluble Silica, Calcium, Phosphorous and Sodium ions which maintain the optimal pH for the

formation of hydroxyapatite on the surface of bioactive glass.²²

In contrast, highest marginal gap exhibited by epoxy resin-based sealer (AH Plus) may be attributed to its setting shrinkage of $0.034\% \pm 0.01\%$, high viscosity, incomplete wetting of dentinal walls due to presence of silicone oil and non-homogenous manual mix. Pronounced shrinkage stresses of epoxy resin-based sealer (AH Plus), causes earlier debonding from the dentinal walls creating gaps.²³

Across all groups, dentinal tubule penetration gradually decreased from coronal to apical thirds, likely due to decreased dentinal tubule density and diameter, increased sclerosis and smear layer accumulation in the apical region restricting sealer penetration.²⁴ Similarly, marginal gaps increased gradually from coronal to apical thirds, owing to oval canal anatomy, presence of atubular dentin, reduced condensation forces and difficulty in uniform sealer application apically.²³ These findings align with study of Sevimay and Dalat reporting superior sealer penetration and adaptation in the coronal two thirds than apical one third of root.²⁵

Scanning Electron Microscope (SEM) was utilised in our study to assess sealer penetration and marginal gaps due to its superior resolution and precise interfacial assessment, overcoming limitations of confocal microscopy related to optical resolution and fluorescent labelling. The study was limited by its in vitro design, immediate obturation and potential SEM artifacts. Overall, the present study demonstrated superior performance of the bioceramic-based sealer (CeraSeal) in aspects of both dentinal tubule penetration and marginal adaptation. Additional in vivo investigations using advanced imaging techniques are required to validate these findings clinically.

Conclusion

Considering the constraints of this study, the bioceramic-based sealer (**CeraSeal**) demonstrated significantly superior dentinal tubule penetration and sealer-dentin adaptation compared with epoxy resin-based (**AH Plus**) and bioactive glass-based (**NISHIKA CANAL SEALER**) sealers. Dentinal tubule penetration was highest coronally and gradually decreased toward the apical third, whereas marginal gaps gradually increased from coronal to apical third. Overall, bioceramic-based sealer (**CeraSeal**) showed the most favorable sealing performance, suggesting its potential for more effective root canal obturation.

Acknowledgment

The authors express their gratitude to Centre for Instrumentation Facility (CIF), IIT, Bhilai, Chhattisgarh for providing access to Scanning Electron Microscope, which greatly facilitated this study.

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Legend Tables and Figures

Table 1: Means and Standard Deviations (SDs) of dentinal tubule sealer penetration and marginal gap in dentin-sealer interface of Groups (n=30).

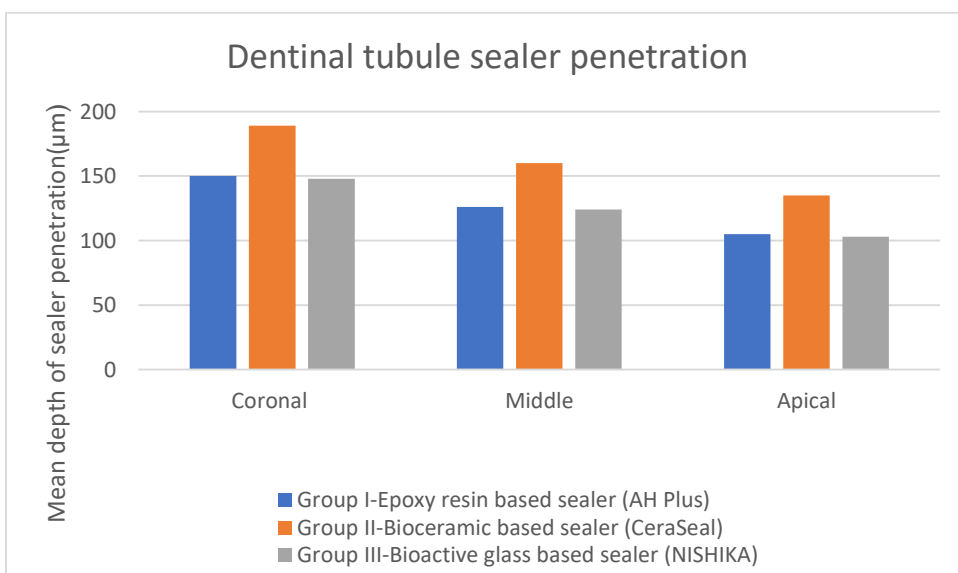
	Descriptive					
		Group	N	Mean	S E	S D
Dentinal tubule sealer penetration	Coronal	Group I	30	150	0.479	2.62
		Group II	30	189	0.525	2.87
		Group III	30	148	0.526	2.88
	Middle	Group I	30	126	0.527	2.89
		Group II	30	160	0.584	3.20
		Group III	30	124	0.847	4.64
	Apical	Group I	30	105	0.551	3.02
		Group II	30	135	0.561	3.07
		Group III	30	103	1.318	7.22
Marginal gap in dentin-sealer interface	Coronal	Group I	30	7.49	0.0482	0.264
		Group II	30	5.02	0.0530	0.290
		Group III	30	5.20	0.0661	0.362
	Middle	Group I	30	8.39	0.0566	0.310
		Group II	30	6.39	0.0504	0.276
		Group III	30	6.55	0.0928	0.508
	Apical	Group I	30	10.79	0.2967	1.625
		Group II	30	7.90	0.0428	0.234
		Group III	30	8.11	0.1089	0.596

Table 2: Tukey Post-Hoc Test to assess individual mean difference amongst the groups. (Intergroup comparison)

				Mean difference	t-value	df	p-value
Dentinal tubule sealer penetration	Coronal third	Group I	Group II	-39.9***	-55.3	87.0	<0.001
			Group III	1.66	2.31	87.0	0.060
		Group II	Group III	41.56***	57.57	87.0	<0.001
	Middle third	Group I	Group II	-33.9***	-35.9	87.0	<0.001
			Group III	1.69	1.79	87.0	0.177
		Group II	Group III	35.57***	37.67	87.0	<0.001
	Apical third	Group I	Group II	-29.7***	-23.7	87.0	<0.001
			Group III	2.56	2.05	87.0	0.108
		Group II	Group III	32.28***	25.75	87.0	<0.001
Marginal gap in dentin-sealer interface	Coronal third	Group I	Group II	2.47***	31.0	87.0	<0.001
			Group III	2.287***	28.73	87.0	<0.001
		Group II	Group III	-0.182	-2.28	87.0	0.064
	Middle third	Group I	Group II	2.01***	20.5	87.0	<0.001
			Group III	1.842***	18.82	87.0	<0.001
		Group II	Group III	-0.164	-1.67	87.0	0.222
	Apical third	Group I	Group II	2.89***	11.1	87.0	<0.001
			Group III	2.681***	10.294	87.0	<0.001
		Group II	Group III	-0.208	-0.799	87.0	0.705

Note. * p < 0.05, ** p < 0.01, *** p < 0.001

Graph 1: Group wise Comparison of dentinal tubule sealer penetration by mean.



Graph 2: Group wise Comparison of marginal gap in dentin-sealer interface by mean.

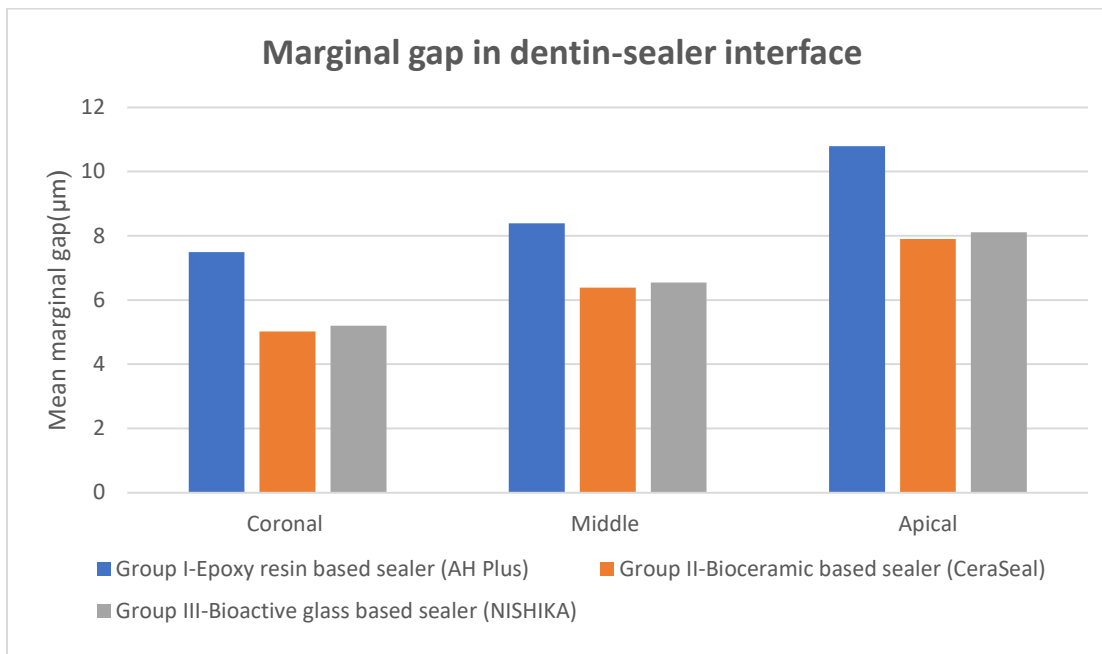


Figure 1: Representative Scanning Electron Microscopic images of samples for dentinal tubule penetration of sealer at 500 X.

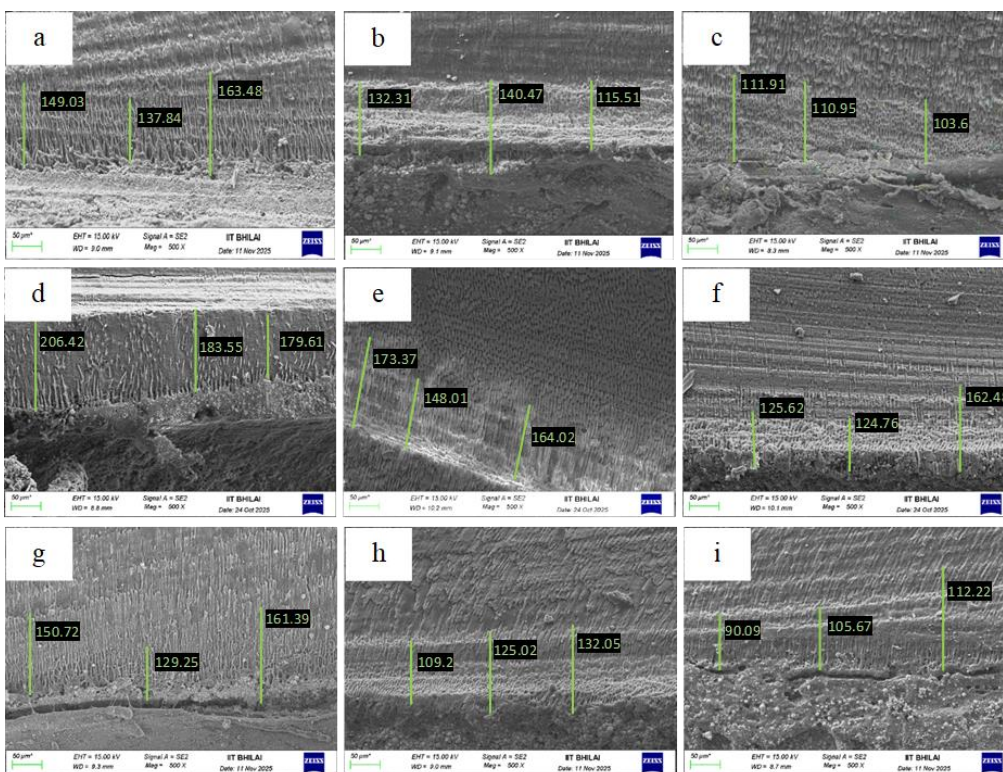


Figure 2: Representative Scanning Electron Microscopic images of samples for marginal gap in dentin- sealer interface at 1500 X.

