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Scanning electron microscopic analysis of tricalcium silicate-based sealer-dentin interface: An *in vitro* study

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Abstract:

Inadequate sealer penetration and weak adhesion to dentin remain major challenges affecting the long-term success of endodontic treatment. Therefore, it is of interest to compare the dentinal tubular penetration and shear bond strength of the tricalcium silicate-based sealer BioRoot RCS with the resin-based gold standard sealer AH Plus using SEM and universal testing methods. Statistically significant differences were observed between the two sealers, with AH Plus showing greater penetration depth and higher shear bond strength values ($p < 0.05$). Mixed failure patterns predominated on debonded surfaces, indicating combined adhesive and cohesive modes of failure in both groups. Thus, data shows the interfacial adaptation and bonding performance of contemporary root canal sealers, thereby supporting evidence-based material selection for enhanced endodontic sealing efficacy.

Keywords: AH Plus, BioRoot RCS, scanning electron microscopy (SEM), sealer penetration, shear bond strength

Background:

Predictable endodontic success necessitates thorough cleaning and shaping followed by a fluid and bacteria-tight seal of the root canal system [1]. However, since gutta-percha does not adhere to the dentinal walls, a root canal sealer is essential to attain a good seal of the root canal system [2]. A root canal sealer enhances the adaptation of the root filling at the dentin-material interface and improves sealing of the endodontic cavity by filling irregular gaps, accessory canals and dentinal tubules that are inaccessible by endodontic instrumentation alone [3]. It is recognised that a large proportion of endodontic treatment failures are frequently attributed to inadequate sealing of the root canal [4]. Reinforcing the need for sealers capable of establishing a fluid-impervious seal between the root canal system and the peri-radicular tissues. An ideal root canal sealer must have high biocompatibility [5]. Satisfactory sealing ability, antibacterial activity and acceptable flow ability, which facilitates deeper penetration into the complex anatomical spaces of the root canal system [6]. Low viscosity and good wetting allow for better intratubular penetration and adaptation into canal irregularities. Increased penetration of the sealer enhances retention, decreases micro-leakage and may exhibit bactericidal action, all of which are necessary for a better clinical outcome [7]. The sealer-dentin bond strength is another critical factor for sustaining the apical seal, as deficient bond strength can contribute to an increased risk of micro leakage and eventual endodontic failure [8]. Epoxy resin-based root canal sealer (AH Plus, DENTSPLY, Germany) has an established record in endodontics and is held as the gold standard [9]. BioRoot RCS (Septodont, Louisville, USA) is a recent bio ceramic water-based sealer, consisting of tricalcium silicate, zirconium oxide and calcium chloride [10]. Therefore, it is of interest to evaluate the sealer-dentin interface, shear bond strength and failure modes of tricalcium silicate-based and epoxy resin-based root canal sealers using scanning electron microscopy.

Materials and Methods:

Thirty extracted human maxillary central incisors were collected and disinfected according to OSHA recommendations. They were cleaned with an ultrasonic device and stored in physiological saline solution until use. The teeth were

decorated using a diamond disc under copious irrigation to yield root sections. All thirty samples were randomly assigned into two groups according to the type of root canal sealer used ($n=15$): Group I (AH Plus) and Group II (BioRoot RCS). Among the fifteen samples per group, ten were tested for SEM analysis and five per group for SBS analysis. Working length was confirmed using #10 K-file with digital radiography. Root canal preparation was performed using ProTaper Gold rotary files up to F3 (30/0.09), with copious irrigation of 5.25% NaOCl between each file. Smear layer removal was achieved using 5 mL of 17% EDTA for one minute, followed by 3 mL of 5.25% NaOCl, with a final rinse of 5 mL saline and canal drying with paper points. The twenty roots were allocated into two groups (AH Plus = 10; BioRoot RCS = 10) and filled using the lateral condensation technique. Sealer-coated master cone gutta-percha was placed to working length. Specimens were incubated at 37°C under 100% humidity for 7 days, then divided transversely with 2 mm sections (first cut: 1.5 mm from coronal surface; last cut: 1.5 mm from apex). After dehydration, cut sections were mounted on aluminium stubs and sputter-coated with gold. Intratubular penetration depth (in micrometres) was measured in the cervical, middle and apical segments using the canal wall as the reference point. The dentinal surfaces of the remaining ten specimens were flattened sequentially with wet 100-, 400- and 600-grit sandpaper (15-second polishing cycles). Each longitudinal section was further cut into coronal, middle and apical thirds; only middle-third specimens were mounted on acrylic blocks. Sealers were prepared per manufacturer's instructions, loaded into syringes and expressed into polyethylene tubes (length = 5 mm; diameter = 3 mm) placed on the polished dentinal surface. Samples were incubated at 37°C for 24 hours before SBS testing. Specimens were loaded on a Universal Testing Machine at a cross-head speed of 1 mm/min; values were recorded in MPa. All data (tubular penetration depth in μm ; shear bond strength in MPa) were analysed using independent t-tests in SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). The Pearson correlation test assessed the correlation between tubular penetration depth and shear bond strength. Statistical significance was set at $p < 0.05$.

Results:

Quantifiable sealer penetration and shear bond strength data were recorded across all specimens. Mean values, standard deviations and SEM images. Group I (AH Plus) showed significantly greater sealer penetration at all three root levels compared to Group II (BioRoot RCS) ($p < 0.001$) (**Table 1**). AH Plus showed significantly greater shear bond strength to dentin than BioRoot RCS ($p < 0.001$), with a mean difference of 7.49 MPa (**Table 2**). The Pearson correlation test revealed no statistically significant correlation between tubular penetration depth and shear bond strength in either group (**Table 3**). SEM analysis of debonded surfaces revealed a high prevalence of mixed failures – cohesive failure at the borders and adhesive failure at the centre – in both groups (**Table 4**).

Table 1: Comparison of the depth of penetration between the study groups

Level	Group	N	Mean (µm)	SD	p-value
Coronal 3rd	AH Plus	10	124	3.23	<0.001*
	BioRoot RCS	10	84.7	2.83	
Middle 3rd	AH Plus	10	91.8	10.3	<0.001*
	BioRoot RCS	10	60.6	5.54	
Apical 3rd	AH Plus	10	39.7	4.69	<0.001*
	BioRoot RCS	10	20.8	2.3	

*Statistically significant ($p < 0.05$); Independent t-test

Table 2: Comparison of shear bond strength between the study groups

Group	N	Mean (MPa)	Mean Diff.	p-value
Total AH Plus	5	9.29	7.49	<0.001*
BioRoot RCS	5	1.8		

*Statistically significant ($p < 0.05$); Independent t-test

Table 3: Correlation between depth of penetration and bond strength

		Coronal 3rd	Middle 3rd	Apical 3rd
Group I (AH Plus)	Pearson Correlation	0.46	-0.53	0.53
	p-value	0.44 (NS)	0.35 (NS)	0.36 (NS)
Group II (BioRoot RCS)	Pearson Correlation	-0.36	-0.44	-0.66
	p-value	0.55 (NS)	0.46 (NS)	0.22 (NS)

NS: Not Significant

Table 4: Comparison of the failure modes between the study groups

Group	Adhesive/Dentin (%)	Mixed (%)	Cohesive/Sealer (%)
AH Plus	30	54	16
BioRoot RCS	10	69	21

Discussion:

The application of root canal sealers with suitable properties adhesion, adaptation and tubular penetration is critical for successful endodontic therapy. The present study comprehensively evaluated and compared the tubular penetration of two types of root canal sealers at the coronal, middle and apical levels and also assessed their shear bond strength. Higher tubular penetration and shear bond strength were exhibited by AH Plus. The deeper penetration can be attributed to the superior flow characteristics of epoxy resin-based sealers, which are derived from their resin content and thin film structure [11]. Several studies have confirmed the superior sealing capacity of AH Plus due to its penetration into surface micro-irregularities. Other studies have also documented the high performance of epoxy resin-based sealers, notably

minimal setting shrinkage, long-term dimensional stability and extended setting time. The lower penetration of BioRoot RCS may be explained by its comparatively high film thickness, which results in reduced flowability [12]. The present study found that the coronal area had the greatest amount of sealer penetration, followed by the middle and apical thirds. This is consistent with systematic review evidence showing that sealer penetration in the apical third is consistently lower than that at the coronal and middle thirds [13]. The regional disparity could be attributed to anatomical complexities in the root canal apex, including uneven dentinal structure, resorption regions, cement-like tissue, atubular dentin, pulp stones and a decrease in tubular size and number. Reduced efficiency of smear layer removal techniques in the apical third may also contribute to this finding [14]. The higher bond strength of AH Plus has been documented in several studies. AH Plus creates covalent bonds between epoxide rings and exposed amino groups within the dentinal collagen matrix, accounting for its excellent adhesion. Long setting time and creep capacity also facilitate mechanical interlocking into micro-irregularities. By contrast, the lower bond strength of BioRoot RCS is attributed to the limited adhesion capacity of tag-like structures formed by apatite precipitation. Comparative push-out bond strength studies have consistently confirmed the superior performance of AH Plus over calcium silicate-based sealers [15]. The use of lateral compaction for obstruction produces a non-homogenous sealer layer along the root canal wall, which may affect sealer penetration into root dentin. The present study additionally assessed failure modes after shear bond strength testing; a high prevalence of mixed failures was observed, with cohesive failure at the borders (near the polyethylene tube) and adhesive failure at the centre of the material. One limitation of the study is that it assessed only the dentin-sealer interface, without evaluating the dentin-gutta percha and sealer-gutta percha interfaces, which represent additional determinants of long-term obturation integrity.

Conclusion:

AH Plus showed superior dentinal tubule penetration and higher shear bond strength compared to BioRoot RCS, with both sealers exhibiting maximum penetration in the coronal third of the root. No significant correlation was observed between tubular penetration depth and shear bond strength. Further studies evaluating long-term clinical behaviour, wettability, dimensional stability and biofilm interactions are recommended to validate the performance of these sealers.

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