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Comparative In-vitro Analysis of Push-Out Bond Strength of Angelus Bio-ceramic and AH Plus Resin-based Root Canal Sealers

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Abstract

Objective(s): This in-vitro study aimed to compare the push-out bond strength of a bioceramic-based sealer (Bio-C Angelus) and a resin-based sealer (AH Plus) on dentinal walls in coronal and apical regions of root canals. **Methods:** 50 extracted single-rooted teeth were randomly assigned into three groups: AH Plus (N=20), Bio-C Angelus (N=20), and the control group (N=10). Each group was further subdivided into two subgroups based on the location (coronal and apical sections). Root canals were filled with gutta-percha and the respective sealers, and push out-bond strength was assessed using four important indices including height, maximum force (Fmax), fracture force (FBreak), and strains at fracture (eBreak) and at maximum force (eFmax). Statistical analysis was performed using one-way ANOVA, followed by Dunnett's post hoc test at $p<0.05$. **Results:** At the apical level, Bio-C Angelus showed significantly lower height, Fmax, FBreak, eBreak, and eFmax compared to AH Plus (all $p<0.05$). At the coronal level, height did not differ significantly between the groups ($p>0.05$), whereas Fmax, FBreak, eBreak, and eFmax were significantly lower in the Bio-C Angelus group (all $p<0.05$). **Conclusion:** Bio-C Angelus exhibited significantly lower push out-bond strength than AH Plus in both coronal and apical regions across all measured parameters. As a result, the use of the AH Plus resin-based sealer may be a better choice in endodontic treatments and could help improve clinical outcomes.

Keywords: Push out-bond Strength; AH Plus; Bio-C Angelus

Introduction

The successful outcome of root canal treatment (RCT) depends primarily on two key factors: thorough canal debridement and effective sealing with an appropriate sealer [1]. Debridement involves meticulous cleaning of the root canal to remove necrotic tissue, infections, and microorganisms, which is essential to prevent reinfection and ensure treatment success [2, 3]. Insufficient removal of microorganisms and defects in the coronal and apical seals after filling are among the main causes of treatment failure [2, 3]. Gutta-percha is the standard filling material used; however, it lacks proper penetration and adhesion to the canal walls [4]. Consequently, sealers play an important role by filling irregular spaces, enhancing the bond between the dentinal walls and filling materials, and significantly contributing to the integrity of the seal [5].

An ideal sealer not only helps in sealing the canal, but also prevents leakage of materials and microorganisms into the root canal system. It should possess specific features, including antimicrobial properties, biocompatibility with living tissues, and dimensional stability [4, 6]. Over the past decade, different types of sealers have been introduced to the market, each with its own characteristics and advantages. These include zinc oxide eugenol sealers, resin-based sealers, glass ionomer sealers, and calcium hydroxide-containing sealers [7, 8]. The quality and properties of the chosen sealer directly influence treatment outcomes. For example, studies have shown that selecting appropriate sealers—such as AH Plus, Tubliseal, or Bio-C Sealer—can increase the success rate of RCT to approximately 96.5% [9, 10].

Bioceramic sealers, such as Bio-C Angelus, and resin-based sealers like AH Plus, have become prominent due to their advantageous biological and physical properties [11]. Bioceramic sealers are highly biocompatible and bioactive, capable of forming chemical bonds with dentin that enhance sealing and support healing. Resin-based sealers are valued for their strong adhesion, stability, and ease of application, providing dependable seals. AH Plus, an epoxy resin sealer, is widely used but lacks bioactive features. Recently, Bio-C Sealer—a bioceramic, non-resin sealer—has been introduced, showing promising bioactivity and biocompatibility, though limited studies are available [11]. While bioceramic sealers exhibit high bond strength and improved dentin bonding, their extensive tubular penetration might complicate future restorations. Ultimately, the bond strength between the sealer and dentin is crucial for preventing leakage and ensuring the long-term stability of root fillings [12, 13].

Differences in the bonding mechanisms of bioceramic and resin-based sealers and their performance in different regions of the root canal, particularly in the coronal and apical segments, warrant further investigation. This study aimed to compare the push-out bond strength of a bioceramic-based sealer (Bio-C Angelus) and a resin-based sealer (AH Plus) in both the coronal and apical regions of human tooth root canals. Since variations in dentinal structure, moisture content, and accessibility can influence sealer adhesion, evaluating their performance in different canal regions is crucial.

Methods

1.1. Sample preparation

This in-vitro experimental study was conducted on extracted single-rooted human teeth. The research was carried out at the Faculty of Dentistry, Shahid Beheshti University of Medical Sciences and Iranian center of Endodontics Research, in Tehran, Iran. It was reviewed and approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences to ensure its ethical compliance (Ethical code: IR.SBMU.DRC.REC.1403.024).

1.2. Inclusion and exclusion criteria

The inclusion criteria for the study included extracted single-rooted teeth (central incisors and premolars), that were free of caries, without fractures, and had a straight and healthy root. Additionally, teeth with closed apices, no internal or external root resorption, and no previous root canal treatment were required. The exclusion criteria involved teeth with developmental defects in the roots, and to ensure eligibility, all teeth underwent periapical radiographs.

1.3. Sample size and grouping

The method for calculating the sample size was based on the standard formula mentioned by Kapoor et al. for comparison of two independent means, which determined a minimum sample size of eight teeth per group. Assuming a 95% confidence level (α = 0.05) and a study power of 80%, the sample size was increased to 10 teeth per group to account for potential sample loss, using the following formula [14].This adjustment was made to account for potential sample loss and to enhance the accuracy of the study results. In total, 50 teeth were included in the study.

$$n > \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2 (S_1^2 + S_2^2)}{(\mu_1 - \mu_2)^2}.$$

The samples were randomly assigned to three groups: AH Plus (N=20), Bio-C Angelus (N=20), and a control group (N=10). Each group was further equally divided into two subgroups of coronal and apical sections:

Coronal-control (N=5), Apical-control (N=5), Coronal-AH (N=10), Apical-AH (N=10), Coronal-Angelus (N=10), and Apical-Angelus (N=10). The sample sizes across all groups showed no significant differences.

1.4. Treatment protocol

All collected extracted teeth were immersed in sodium hypochlorite (NaOCl) solution for 10 minutes to remove residual soft tissue and debris. The crowns were then sectioned at the cementoenamel junction (CEJ) using a diamond disk under water cooling, resulting in root specimens with a minimum length of 14 millimeters. The working length was established by inserting a #10 K-file until the tip appeared at the apical foramen, then subtracting 1 millimeter from this measurement. Root canal preparation was performed using ProTaper rotary files on a hand piece employing a crown-down technique. Specifically, in this study, we used the ProTaper SP1 Gold model. The main features of this file include a length of 25 mm, a rotational speed of 300 to 350 rpm, made from nickel-titanium (NiTi) alloy, a torque of 2 Newton-centimeters, and a packaging of 6 pieces per pack. Subsequently, sequential use of SX, S1, S2, F1, and F2 files was conducted to the full working length, ensuring thorough cleaning and shaping. During instrumentation, each canal was irrigated with 2 mL of physiological saline solution after each file. This was followed by irrigation with 10 mL of 2.5% NaOCl for 15 minutes to disinfect the canal. The smear layer was then removed with 17% ethylene diamine tetra acetic acid (EDTA) for 3 minutes, followed by a 1-minute rinse with NaOCl. Finally, the canals were rinsed with 10 mL of distilled water to eliminate residual chemicals.

For the obscuration process, the roots were filled based on the type of sealer in each group: Group 1: Bioceramic sealer (Bio-C Sealer, Angelus) combined with gutta-percha, Group 2: Resin-based sealer (AH Plus) combined with gutta-percha, and Group 3: Gutta-percha alone, serving as the control group. Sealers were prepared according to the manufacturers' instructions, and root canals were filled using the single cone technique. The filled roots were stored in 100% humidity at 37°C for 24 hours to allow for complete setting. Subsequently, the roots were sectioned transversely with a diamond disk under water cooling to obtain slices of 2 mm thickness from both the coronal and apical regions. The thickness of each slice was measured with a calibrated caliper to ensure consistency. Following sectioning, the roots underwent a push-out bond strength test.

The push out- bond strength between the sealer and dentin was evaluated using the push-out test, and was assessed using the height, maximum force (Fmax), fracture force (FBreak), and strains at fracture (eBreak) and at maximum force (eFmax). The Push-Out Bond Strength test evaluates two key parameters: Fmax (maximum force) and Emax (maximum energy). Fmax measures the peak force a sample can withstand before complete deboning, indicating the initial bonding strength, and is used to assess the resistance of adhesive materials to immediate forces. Conversely, Emax represents the total energy absorbed until failure, reflecting the material's toughness and ability to deform plastically, which influences durability and resistance to crack propagation. Clinically, materials with high Fmax are desirable for strong initial adhesion, while those with high Emax are preferred for resisting repetitive stresses and preventing brittle failure. Balancing both parameters is crucial in dental material design to optimize both bond strength and toughness, ensuring long-term stability and performance. Treatment protocol is shown in Figure 1.

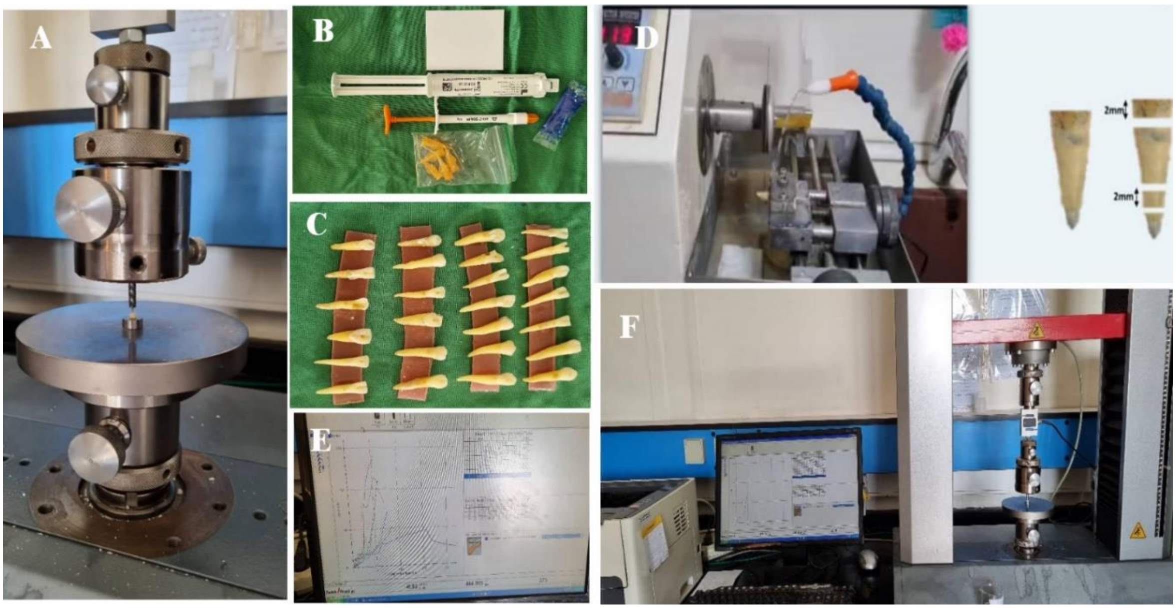

Figure 1: Treatment protocol. A; push out test step using the Instron bar, B; 2 types of sealers: AH Plus and Angelus Bioceramic, C; The samples, D; Preparation of coronal and apical sections of the root canal, E and F; registration of push out- bond strength measures

2.5. Statistical analysis

All statistical analyses were conducted using SPSS version 21, with a significance level set at $P < 0.05$. Additionally, Prism version 8 was utilized for creating figures. Descriptive statistics, including tables and graphs, were utilized to clearly present the findings. The normality of the distributions for height, Fmax, FBreak, eBreak, and eFmax was evaluated using the Kolmogorov-Smirnov test. For variables that followed a normal distribution, push out- bond strength between AH Plus, Bio-C Angelus, and a control group comparisons of parameters such as height, Fmax, FBreak, eBreak, and eFmax were conducted using one-way ANOVA, followed by Dunnett's post hoc test to determine specific group differences. These analyses were carried out to ensure the accuracy and reliability of the results.

Results

Comparison of central and dispersion indices (mean and standard deviation) for the five variables — Height, Fmax, FBreak, eBreak, and eFmax — in the studied groups in the apical and coronal sections is presented in Table 1. The apical-control and coronal-control groups received gutta-percha alone, without any sealer (resin-based or bioceramic); therefore, they served as the baseline reference for comparison with the AH Plus and Bio-C Angelus groups. According to the Kolmogorov-Smirnov test, the distribution of data in both the apical and coronal sections among the study groups was normal for all five variables.

Table 1- Central and dispersion indices (Mean, SD) for Height, Fmax, FBreak, eBreak, and eFmax among the studied groups in the apical and coronal sections

Region	Variable	Group	N	Mean	SD
Apical	Height	Apical-control	5	0.61	0.33
		Apical-AH	10	1.33	0.29
		Apical-Angelus	10	0.65	0.27
		Total	25	0.91	0.44
	Fmax	Apical-control	5	186.83	47.28
		Apical-AH	10	180.54	76.68
		Apical-Angelus	10	97.16	56.37
		Total	25	148.44	74.84
	FBreak	Apical-control	5	186.20	48.29
		Apical-AH	10	163.47	84.69
		Apical-Angelus	10	89.79	56.15
		Total	25	138.54	77.35
	eBreak	Apical-control	5	0.88	0.26
		Apical-AH	10	0.97	0.39
		Apical-Angelus	10	0.48	0.17
		Total	25	0.75	0.36

Countinious table 1

	eFmax	Apical-control	5	0.88	0.26
		Apical-AH	10	0.85	0.25
		Apical-Angelus	10	0.47	0.16
		Total	25	0.70	0.29
Coronal	Height	Coronal-control	5	0.04	0.33
		Coronal-AH	10	1.41	0.39
		Coronal-Angelus	10	1.39	0.42
		Total	25	1.13	0.67
	Fmax	Coronal-control	5	80.53	69.17
		Coronal-AH	10	218.19	129.10
		Coronal-Angelus	10	24.91	46.42
		Total	25	113.34	126.17
	FBreak	Coronal-control	5	78.30	70.51
		Coronal-AH	10	228.07	151.18
		Coronal-Angelus	10	6.40	6.68
		Total	25	90.88	128.24
	eBreak	Coronal-control	5	0.41	0.22
		Coronal-AH	10	1.74	1.01
		Coronal-Angelus	10	0.58	0.40
		Total	25	0.89	0.83
	eFmax	Coronal-control	5	0.36	0.24
		Coronal-AH	10	2.05	0.86
		Coronal-Angelus	10	0.57	0.78
		Total	25	1.12	1.06

As illustrated in Figures 2 and 3, Bio-C Angelus showed significantly lower values across all parameters at the apical level, and for all parameters except height at the coronal level (see Table 2 for exact p-values).

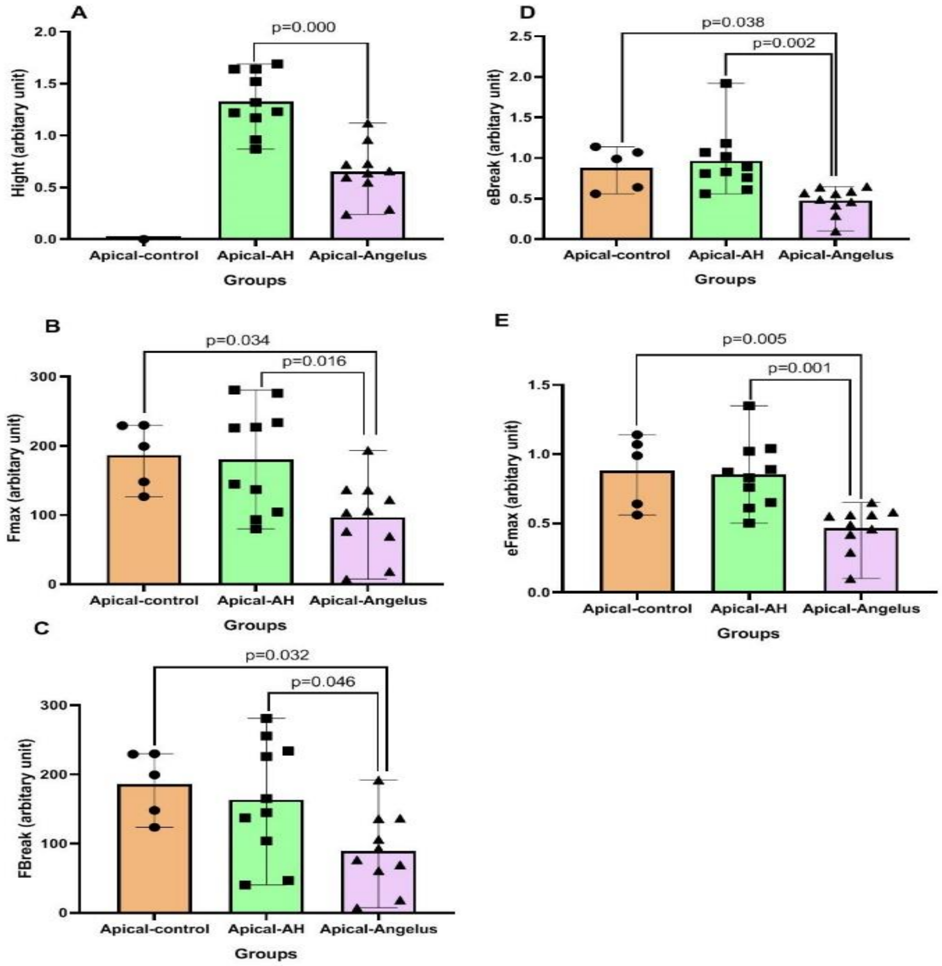

Figure 2: Comparison of the Height (A) Fmax (B), FBreak (C), eBreak (D), and eFmax (E) between Bio-C Angelus and AH Plus Groups at the apical Level. FBreak , Fracture Break; Fmax, maximum force; eFmax, effective maximum force; eBreak, Environmental Fracture Break

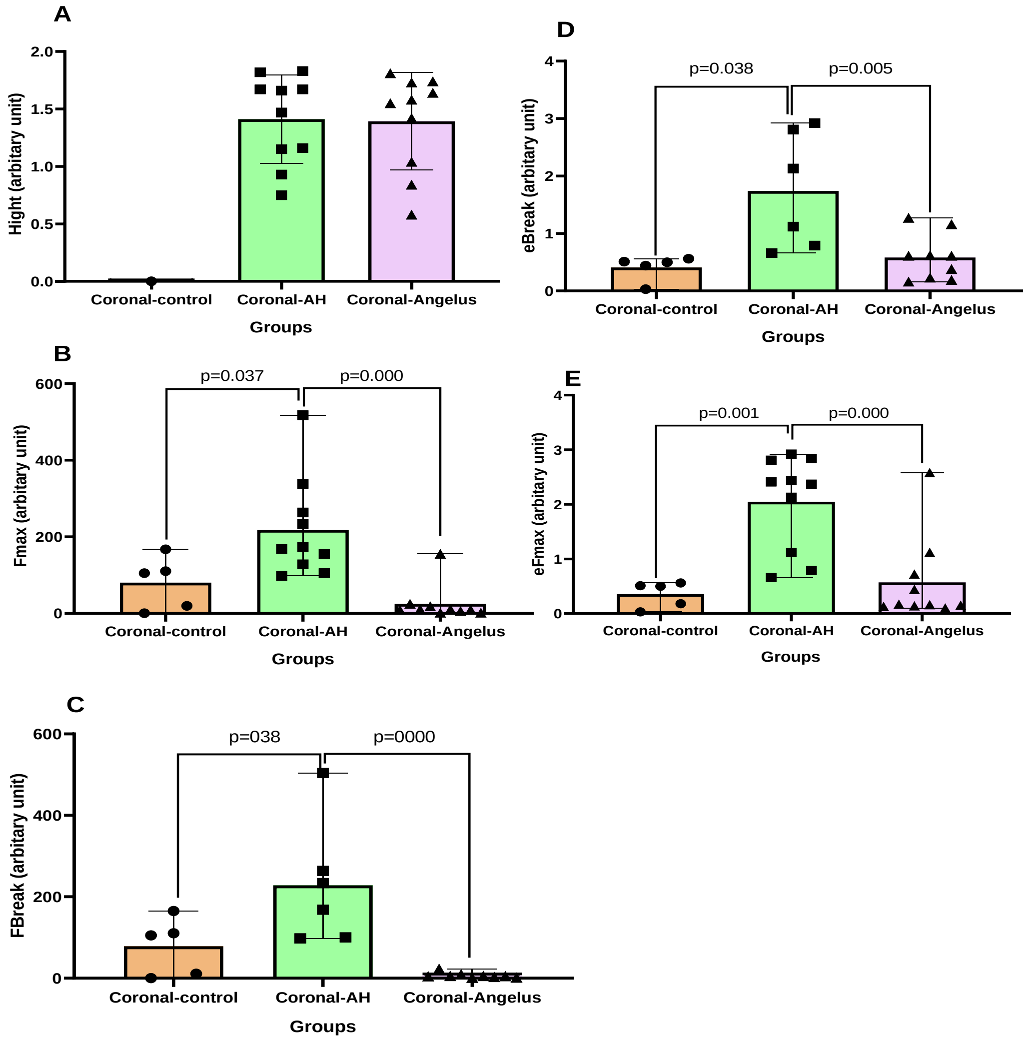

Figure 3: Comparison of the Height (A) Fmax (B), FBreak (C), eBreak (D), and eFmax (E) between Bio-C Angelus and AH Plus Groups at the coronal Level. FBreak , Fracture Break; Fmax, maximum force; eFmax, effective maximum force; eBreak, Environmental Fracture Break.

Table 2 shows the mean of Height, Fmax, FBreak, eBreak, and eFmax among the studied groups in both the apical and coronal sections, along with the corresponding P-values. At the apical level, the mean Height and eBreak were highest in the Apical-AH group, while the mean Fmax, FBreak, and eFmax were highest in the Apical-control group. At the coronal level, the mean of all five variables was highest in the Coronal-AH group. ANOVA testing showed statistically significant differences between the groups for all variables in both sections (all P<0.05). Post hoc pairwise comparisons indicated that the mean differences between the Angelus and AH groups were statistically significant in both the apical and coronal sections, and that the differences between the Coronal-AH and Coronal-control groups were also statistically significant.

Table 2- Mean difference and statistical significance (P-value) of the variables Height, Fmax, FBreak, eBreak, and eFmax in the studied groups in the apical and coronal section

Region	Variable	Group	N	Mean	P-value
Apical	Height	Apical-control	5	0.61	0.000
		Apical-AH	10	1.33	
		Apical-Angelus	10	0.65	
		Total	25	0.91	
	Fmax	Apical-control	5	186.83	0.013
		Apical-AH	10	180.54	
		Apical-Angelus	10	97.16	
		Total	25	148.44	
	FBreak	Apical-control	5	186.20	0.024
		Apical-AH	10	163.47	
		Apical-Angelus	10	89.79	
		Total	25	138.54	

Continuous table 2

	eBreak	Apical-control	5	0.88	0.003
		Apical-AH	10	0.97	
		Apical-Angelus	10	0.48	
		Total	25	0.75	
	eFmax	Apical-control	5	0.88	0.001
		Apical-AH	10	0.85	
		Apical-Angelus	10	0.47	
		Total	25	0.70	
Coronal	Height	Coronal-control	5	0.04	0.000
		Coronal-AH	10	1.41	
		Coronal-Angelus	10	1.39	
		Total	25	1.13	
	Fmax	Coronal-control	5	80.53	0.000
		Coronal-AH	10	218.19	
		Coronal-Angelus	10	24.91	
		Total	25	113.34	
	FBreak	Coronal-control	5	78.30	0.001
		Coronal-AH	10	228.07	
		Coronal-Angelus	10	6.40	
		Total	25	90.88	
	eBreak	Coronal-control	5	0.41	0.003
		Coronal-AH	10	1.74	
		Coronal-Angelus	10	0.58	
		Total	25	0.89	
	eFmax	Coronal-control	5	0.36	0.000
		Coronal-AH	10	2.05	
		Coronal-Angelus	10	0.57	
		Total	25	1.12	

P-value: one-way ANOVA result comparing the control, AH Plus, and Bio-C Angelus groups for each variable within each region.

Discussion

The present study investigated the push-out bond strength of a bioceramic-based sealer (Bio-C Angelus) and a resin-based sealer (AH Plus) in both the coronal and apical regions of human tooth root canals. The findings revealed that at the apical level, Bio-C Angelus group exhibited significantly lower values for height, Fmax, FBreak, eBreak, and eFmax compared to the AH Plus group. In contrast, at the coronal level, the height in the Bio-C Angelus group showed no significant difference from that in the AH Plus group. However, the values for Fmax, FBreak, eBreak, and eFmax were all reduced in the Bio-C Angelus group compared to the AH Plus group. Overall, the study demonstrated that AH Plus had significantly higher push-out bond strength than Bio-C Angelus in both the coronal and apical regions.

Similar to the present study, several other studies, including Verma et al.[15], Donnermeyer et al [16, 17]., and Dibaji et al [18]., have found that epoxy resin-based sealers like AH Plus generally exhibit higher bond strength compared to bioceramic sealers such as BioRoot RCS and TotalFill BC Sealer HiFlow. The above-mentioned studies primarily employed in-vitro experimental designs to evaluate and compare the bond strength of various root canal sealers and their ability to penetrate dentinal tubules, with all being laboratory-based experiments conducted under controlled conditions. Among these, Verma et al [15]. utilized a single-blinded design to reduce bias during outcome assessment, focusing on experimental evaluation of bond strength through measurements of push-out bond strength, which reflects the adhesion quality of sealers to dentinal walls.

In previous studies, different devices and methods have been used for comparison, including the universal testing machines (UTMs) [18-21]. to apply controlled forces to root canal samples until bond failure occurs, providing quantitative measurements in MPa. Additionally, microscopic techniques such as confocal laser scanning microscopy or scanning electron microscopy (SEM) have been employed, especially by Verma et al [15]. to visualize and measure the extent of sealer penetration into dentinal tubules.

These present results are attributed to AH Plus's ability to form covalent bonds with dentinal collagen, resulting in a stronger chemical adhesion; while bioceramic sealers bond mainly through hydroxyapatite formation with dentinal collagen, presenting the weakness of this sealer. Resin sealers also penetrate deeper into dentinal tubules due to their better flow characteristics and reduced shrinkage, enhancing contact and bonding [14, 15]. Additionally, AH Plus shows better adhesion to gutta-percha and is less affected by environmental factors, whereas bioceramic sealers may lose bond strength under certain conditions. Studies like Verma et al. highlight that BIO-C ION achieves the highest tubule penetration, while AH Plus demonstrates superior push out-bond strength. Overall, endodontic material selection is crucial, as factors such as the sealer type, setting time, and environmental conditions influence bond strength [15, 17, 18]. The findings emphasize the importance of considering these variables to optimize endodontic treatment outcomes, though some researches have conflicting results, indicating the need for further comprehensive investigations.

In contrast to the present study, some other studies such as those by Karobari et al. [19] , Khoury et al. [20], Cimpean et al. [21], and Retana-Lobo et al. [22], have concluded that Bio-C sealers—such as BioRoot RCS and TotalFill BC Sealer HiFlow—exhibit higher bond strength than epoxy resin-based sealers like AH Plus, due to their ability to form micromechanical bonds and calcium ion release. The study by Karobari et al. [19] investigated three key aspects of root filling materials—push-out bond strength, dentinal tubule penetration, and adhesion patterns—though these were not directly assessed in the current research. The study by Karobari et al [19]. used push-out bond strength tests, microscopy techniques (like SEM or CLSM) for dentinal tubule penetration, and interface analysis via microscopy to investigate the adhesion patterns of root filling materials. Some researches have indicated that higher bond strength, especially evident with Bio-C Angelus in the apical region, suggests a more durable and resistant filling [22]. They have also presented effective dentinal tubule penetration by Bio-C Angelus enhancing the seal and reducing fluid or bacterial leakage, contributing to better clinical outcomes. Adhesion patterns, whether mechanical or chemical, influence the stability and longevity of the sealers, with bioceramic and resin-based sealers behaving differently across different root regions. Previous studies, such as Cimpean et al. [21], demonstrated the superiority of bioceramic sealers over resin-based ones in terms of the bond strength, while Retana-Lobo et al. [22] found BioRoot™ RCS outperforming EndoSequence BC, especially regarding calcium ion release.

In this study, the push out-bond strength of AH Plus exhibited superior bond strength compared to Bio-C Angelus, especially in the apical region. Supporting this, Allabban et al. [23]investigated bond strength in different root canal regions, finding that the coronal area generally has higher bond strength due to a denser tissue and structural differences, while apical regions tend to have lower bond strength. Their findings emphasized the importance of understanding root canal anatomy and its influence on treatment outcomes. Cimpean et al. [21] further confirmed that variations in bond strength across different regions of the root canal can impact the sealing quality and treatment success, with lower bond strength associated with higher failure rates. Further research should be warranted to explore these sealers' performance in clinical settings and their long-term durability under functional loads.

Conclusion

At the apical root level, the values for height, Fmax, FBreak, eBreak, and eFmax were all lower in the Bio-C Angelus group compared to the AH Plus group. At the coronal level, the height in the Bio-C Angelus group did not show a significant difference compared to the AH Plus group. However, the Fmax, FBreak, eBreak, and eFmax values were all lower in the Bio-C Angelus group compared to the AH Plus group. The study demonstrated that AH Plus exhibited significantly higher push out- bond strength compared to Bio-C Angelus in both coronal and apical regions. These findings highlight the potential advantages of using AH Plus as a preferred sealer material in endodontic procedures, emphasizing its efficacy in both coronal and apical regions and across various testing conditions.

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Informed Consent Statement: Written informed consent was obtained from the patient for the publication of this case report and any accompanying images.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy or ethical restrictions.

Using AI: Generative AI tools were used solely to assist with language editing and grammar checking.

Conflict of Interest: The authors declare that they have no competing interests.

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