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EFFECT OF ENDODONTIC BIOCERAMIC SEALER VERSUS RESIN BASED SEALER IN THE BOND STRENGTH OF FIBER POSTS LUTED WITH RESIN CEMENT TO ROOT DENTIN (AN IN-VITRO STUDY)

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ABSTRACT

Purpose: To evaluate Well-Root ST and Expoxidin Duo sealers' contact angle, dentinal tubule penetration, and their impact on fiber post-bond strength.

Materials and Methods: Fifty-eight maxillary central incisor teeth were collected and decoronated. Ten teeth were longitudinally split into 20 segments and treated with bioceramic (Well-Root ST) and epoxy resin-based (Epoxidin Duo) sealers (n=10 per group) to evaluate the contact angle. Forty-eight teeth were divided into two groups (n=24) based on the same sealers used for obturation. Both obturated teeth groups were subdivided into two subgroups based on the evaluating test; 14 specimens were assessed for dentinal tubule penetration using a scanning electron microscope (SEM), and 10 specimens were restored with fiber posts and cross-sectioned to evaluate the push-out bond strength using a universal testing machine. Failure mode was determined for pushed-out slices under a SEM. Independent t-test was used to compare two different groups. One-Way ANOVA and Tukey's Post Hoc tests were used for multiple comparisons. $P < 0.05$ was the significance level.

Results: Epoxidin Duo group showed a significantly higher contact angle (56.78 ± 0.68^{o}) than Well-Root ST group (53.25 ± 0.25^{o}). Well-Root ST group showed significantly higher dentinal tubule penetration ($10.40 \pm 1.05\ \mu m$) than Epoxidin Duo group ($7.61 \pm 1.08\ \mu m$). Both groups showed a non-significant push-out bond strength difference.

Conclusions: Bioceramic sealer showed higher wettability and dentinal tubule penetration than epoxy resin-based sealer. However, both sealers affected the fiber post-bond strength at various regions throughout the root canal length without influencing the total bond strength.

KEYWORDS: Endodontic sealer, Fiber post, Contact angle, Dentinal tubule penetration, and Push-out bond strength.

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INTRODUCTION

When the dental crown is severely damaged, restoring endodontically treated teeth becomes complicated. In these circumstances, root canal treatment is required to cement an intra-radicular post and preserve the coronal restoration. Obturation mainly targets sealing the root canal to avoid irritant leakage to the periapical area, affecting tooth survival.[1] However, the obturation material properties and coronal restoration influence the seal.[1]

Besides acting as an antimicrobial agent against various periodontal microbes, the ideal endodontic sealer should provide a complete microscopic seal so bacteria cannot pass through the root canal system.[2] Epoxy resin-based sealers were used in endodontics as a gold standard. Because of their outstanding physical qualities, acceptable biological performance, apical sealability, reduced solubility, and micro-retention to root dentin, epoxy resin-based sealers have been widely employed. Furthermore, it demonstrated improved wettability to dentine and gutta-percha and superior handling properties.[3]

Calcium silicate- or bioceramic-based sealers were introduced, exhibiting a hydrophilic nature, alkaline pH, insolubility, and dimensional stability on setting and in water or humid conditions. Calcium silicate sets by reaction with the water supplied by tissue fluids which promotes a strong bond between bioceramic sealers and root dentin as biomineralization (hydroxyapatite formation) occurs.[4,5]

Posts and cores are frequently employed to restore root-filled teeth with significant coronal tooth structure loss. Clinicians are concerned about the stability and durability of post-restoration, as most clinical failures in endodontic post systems were caused by de-cementation of the post and/or root fractures.[6] Fiber-reinforced composite (FRC) posts have recently emerged to restore endodontically treated teeth due to their physical characteristics equivalent to the tooth structure and their displaying of optimum stress distribution.[7,8] They reduced root fractures; therefore, the longevity of FRC posts after being resin cemented relies on the strength of the bond between the post, cement, and root dentin in which most failures occur.[9,10] Thus, it is essential to investigate the factors restricting the root canal wall's capacity to adhere to resin cement.[11]

According to the adhesive method, three strategies are frequently used for fiber post-cementation: etch-and-rinse adhesive systems, self-etching primers, and self-adhesive cement. The resin cement commonly used for FRC posts cementation are self-etch adhesive systems because they offer a more straightforward bonding process, higher bond strength, and better marginal adaptation than resin cement that require pretreatment for dentin walls before cementation.[6,12]

The type of endodontic sealer employed for canal obturation may impact how the resin cement and dentin interact where dentinal tubules penetration of the sealer makes it part of the canal wall even after post-space preparation.[11] Furthermore, measuring the contact angle that expresses the spread of a liquid on a solid surface gives better knowledge about endodontic sealer and root dentine interactions. The contact angle is inversely proportional to wettability.[13]

The goal of this in-vitro study was to evaluate the contact angle and dentinal tubule penetration depth of a bioceramic sealer (Well-Root ST; Vericom, Gangwon-Do, Korea) compared to an epoxy resin-based sealer (Expoxidin Duo; Tehno-Dent, Belgorod, Russia) as well as their impact on the bond strength of fiber post cemented by a self-adhesive resin cement. The null hypothesis was that the bioceramic sealer would show a lower contact angle and higher dentinal tubule penetration leading to the higher bond strength of cemented fiber post.

MATERIALS AND METHODS

Sample size calculation

Based on prior studies and using a power of 80% and a type I error probability of 0.05, the estimated sample size for each investigation was determined in the present study.[14-16] Ten specimens per group were determined to investigate the contact angle when normally distributed responses within each group had 0.91 standard deviation (SD) and an estimated mean difference (MD) of 1.2. While 14 specimens per group were determined to assess the dentinal tubular penetration when normally distributed responses within each group were 25.28 SD and 28 MD. In addition, ten specimens were determined per group to evaluate the push-out bond strength, where the estimated MD and SD were 1.65 and 1.24, respectively.

Specimen preparation

The research ethics committee approved the study (No. RECO6U/17-2019) at the Faculty of Dentistry, October 6 University, Giza, Egypt. Fifty-eight extracted upper central incisor teeth for periodontal reasons were collected. All teeth were investigated for cracks and resorption under magnification of 2.5× using a surgical microscope (SOM 62, Karl Kaps, Ablar, Germany). Labial and proximal perspective radiographic examination was performed to confirm the integrity of the apical foramen and single canal presence.

All teeth were decoronated at the cementoenamel junction (CEJ) with a diamond disc (Buehler, Lake Buff, IL, USA) to have a total length of 15 mm. Then, K-file #15 was used to test the canals' patency, followed by working length (WL) determination at 14 mm.

The list of materials used in this study is summarized in Table (1).

Contact angle analysis

Ten upper central incisor teeth were randomly selected for contact angle assessment. The roots were split into 20 longitudinal slices/segments (n=10/group). 0.6 mm diamond disc mounted on a cutting machine (IsoMet 4000 micro-saw; Buehler, IL USA) at 10 mm/min feeding rate and 2500 rpm

TABLE (1): Used materials and their compositions.

Materials	Manufacturer	Composition	Batch	Mixing
Well-Root ST	Vericom, Chuncheon, Korea	Calcium silicate compound, calcium sulfate dehydrates, calcium sodium phosphosilicate, zirconium oxide, titanium oxide and thickening agents	WR980100	Single paste in syringe
Epoxidin Duo	TehnoDent, Belgorod, Russia	Epoxy resin, amine hardener curing agent, fillers, plasticizer, and zirconium oxide as a radiopaque additive, 25-50 bisphenol A/epichlorohydrin resin and 2.5-10 bisphenol F/epichlorohydrin copolymer	25068-38-6	Two-pastes
G-CEM	GC , Tokyo, Japan	Powder: Fluoro–alumino–silicate glass, initiator and pigment Liquid: UDMA, dimethacrylate, 4-META, distilled water, phosphoric acid ester monomer, silicon dioxide, silica powder, initiator, inhibitor and stabilizer	0610141	Capsules
Glassix Plus	Nordin, Montreux, Switzerland	Epoxy matrix (ethoxyline) 25-35% and Glass fibers 65-75%	04-1108 01	-

speed was used to refine the slices to create a 10 mm standard segment length. To eliminate any surface scratches, each segment was polished with 400–600 grit polishing papers (CarbiMet; Buehler, IL, USA). Then, all specimens were ultrasonically cleaned in water for 5 min.

The wettability of sealers was evaluated by determining the contact angle formed between a drop of sealer and the root dentin surface. The sealers were prepared following the manufacturers' recommendation. Afterward, they were poured into an insulin syringe. A predetermined amount (0.1 ml) of each sealer was applied to the root segment and kept in standard environmental conditions until fully set.

Shadowing and semi-reflection techniques were utilized to measure the contact angle using a vertical profile projector (PJ-A3000; Mitutoyo, Illinois, USA), applying optical principles in the inspection. Each specimen was fixed to the horizontal projector table to produce a visible shadow projection using 10× magnification. The profile projector is adjusted to measure the angle generated between the sealer droplet and root dentin.[17]

Fig. (1) Contact angle analysis using a vertical profile projector.

Specimen's root canal obturation

Root canal preparation was performed for 48 decoronated teeth using one reciprocating shaping file (RECIPROC, 40/0.06; VDW, Munich, Germany). Before inserting the file used in canal preparation, 2.5 ml of 2.6% sodium hypochlorite (NaCl) was injected for irrigation. After instrumentation, 5 ml of 2.6% NaCl with ultrasonic activation (IRR20-21, Satelec, Acteon, France) for 30 sec was performed. Next, 5 ml 17% Ethylenediaminetetraacetic acid (EDTA) (MD-ChelCream; META BIOMED Co., Chungbuk, Korea) for 60 sec was applied, followed by final irrigation with 5 ml normal saline solution. All teeth roots were incubated at 37°C for 24 hrs and 100% humidity to simulate the normal intraoral environment.[18]

According to the utilized obturation sealers, specimens were divided randomly into two groups (n=24); Group I: specimens were obturated with a single cone and calcium silicate/bioceramic based sealer (Well-Root ST; Vericom, Chuncheon, Korea) and Group II: specimens were obturated with a single cone and epoxy resin-based sealer (Epoxidin Duo; TehnoDent, Belgorod, Russia).

For Group I, each specimen's root canal was irrigated with distilled water as the bioceramic sealer material requires moisture for setting. Therefore, the canal was not adequately dried with paper points, but only the moisture was decreased to avoid setting retardation or sealer dilution. The obturation was done using the hydraulic obturation technique. After a master cone (Meta Biomed Gutta Percha Points, 0.06 T, size 40; META BIOMED Co., Chungbuk, Korea) insertion and WL and tug-back checking, Well-Root ST sealer was injected to fill the whole canal, and then the master cone was reinserted. A pumping motion was applied to ensure sealer flow over the canal walls and into the dentinal tubules. Extra obturation material was eliminated with a hot condenser, and vertical condensation was performed to the coronal 2 mm of the root canal using an endodontic hand plugger.

For Group II, each specimen's root canal was appropriately dried using sterile paper points. A master cone (Meta Biomed Gutta Percha Points, 0.06 T, size 40; META BIOMED Co., Chungbuk, Korea) was inserted then WL and tug-back were checked. The Epoxidin Duo sealer was mixed and then applied to the master cone, which was later inserted inside the canal until it reached the apical constriction. A pumping motion was used to ensure the sealer flow. Finally, excess filling material was discarded, and vertical condensation was performed, as previously mentioned.

The obturation was radiographically checked using labial and proximal view radiographs. To permit the full sealers setting, the orifices of specimens were filled using an adhesive (Scotchbond; 3M ESPE, Deutschland Neuss, Germany) and a resin composite (3M Filtek Z250 XT, 3M, St Paul, USA) following the manufacturer's instructions. They were kept at 37 °C and 100% humidity for 7 days to ensure the complete set of tested sealers.[19]

Dentinal tubules penetration measurement

After incubation, each specimen was positioned horizontally in a resin (Technovit 4071; Hereaaus Kulzer, Hanau, Germany). It was cut perpendicular to its long axis by a diamond cutter (RB205 Metsaw-LSTM; R&B, Daejeon, Korea) at 500 rpm with constant water cooling. The specimens were cut into 1 mm (± 0.1 mm) thick slices at 5 to 6 mm, 8 to 9 mm, and 11 to 12 mm from the apex. For smear layer removal, all specimens were rinsed using 5 ml of 17% EDTA, 5 ml of 5.25% NaOCl, and 5 ml of normal saline for 60 sec, respectively. No ultrasonic irrigation was undertaken to avoid artifacts caused by sealer removal from the tubules.[20] Finally, the prepared slices were dried.

The penetration of sealers was assessed using a scanning electron microscope (SEM) (Quanta FEG 250, FEI, Oregon, USA). Each slice was fixed on aluminum tubs and sputter-coated with a gold coating (SCD050 Sputter Coater, BAL-TEC, PA, USA). Then, it was captured at a magnification of 1600× to note the maximum sealer penetration depth. The materials pushed into the dentinal tubules were identified via EDX analysis because the evaluated sealers contain zirconium oxide as a radiopacifier.

Push-out bond strength testing

After 7 days of incubation, resin composite orifice sealing was removed. A post-space preparation was performed in the root canal of each specimen. Using Gates Glidden drills (#2 and 3; Maillefer, Dentsply, Oklahoma, USA), gutta-percha was removed from the root to a depth of 10 mm maintaining approximately 5 mm of gutta-percha for an apical seal. The specified drill (Nordin Glassix Plus, size 3; Nordin Dental, Switzerland) was used to enlarge the root canal to receive a fiber post (Nordin Glassix Plus, size 3; Nordin Dental, Switzerland). Then the length was checked radiographically.

Each post space was irrigated by 5 ml of 17% EDTA, followed by 5 ml of 5.25% NaOCl, and finalized by 5 ml of saline for 60 sec. The post space was then desiccated with paper points. For post-cementation, a self-adhesive resin cement capsule (G-Cem; GC, Luzern, Switzerland) was mixed for 10 sec (VIBRAMIX VB-4000, 3TECH, Kent, UK). Then, the post was coated with cement and inserted into the prepared post space. Light curing was applied (Brelux Power Unit; Bredent, Senden, Germany) at the orifice of each specimen for 10 sec to allow setting of the superficial cement layer, while the deep layers were left to allow chemical curing for 5 min at 37°C in accordance to manufacturer instructions.

All tested specimens were entirely immersed in clear acrylic resin. Then, each specimen was sectioned perpendicular to the post-long axis by a 0.6 mm diamond disc mounted on a cutting machine (IsoMet 4000 micro-saw, Buehler, IL, USA) at a 10 mm/min feeding rate and 2500 rpm speed under abundant water-cooling. In each specimen, the post-space region was divided into 9 slices of 1 mm (± 0.1 mm) thickness from each third (coronal, middle, and apical).[21] Using a stereomicroscope (Nikon Eclipse MA100 Inverted; Nikon, MA, USA), each cross-section slice was examined to identify any dentin fracture or filling material gap before push-out bond strength evaluation.

A universal testing machine (Instron 3345 5kN, Instron Industries, MA, USA) supplied with a 0.9 mm stainless-steel plunger on its upper compartment applying a load to the fiber post region without any strain on the surrounding dentin was used. An apicocoronal orientation for each slice was employed to push the fiber post towards the slice's big diameter, preventing post-movement limitation.[21,22] The underlying dentin was properly supported throughout the compressive load. A compressive mode force was applied to the apical aspect of each slice until the specimen failed using a 500 N load cell and a cross-head speed of 1 mm/min. The maximum failure load was calculated. The bonding area was calculated using the formula for the lateral surface area of a conical frustum: $SL= \pi (r_1 + r_2) [\sqrt{(r_1 + r_2)^2 + h^2}]$, where SL is the lateral bonded surface area, R is the post's coronal radius, r is the post's apical radius, and h is the height/thickness of the slice. The force (F) required to displace the post was measured in kilo-Newtons (kN), converted to Newton (N), and divided by the post's lateral area (SL) in mm^2 to compute the bond strength in megaPascals (MPa) using the equation: BS = F/SL.[21]

Failure mode analysis

All slices were inspected under a SEM (Quanta FEG 250, FEI, Oregon, USA) at 150× magnification following pushed-out testing to determine failure modes.[23] Failures could be adhesive between the fiber post and cement; adhesive between the cement and root dentin; cohesive in dentin; cohesive in the cement; and mixed when the failure occurred at both the fiber post/resin cement interface and the cement/root dentin interface in the same specimen.

Statistical analysis

All data were presented as a mean and standard deviation. Shapiro-Wilk and Kolmogorov-Smirnov tests were used to explore data normality revealing a normal distribution (parametric data) as a P-value >0.05. Independent t-test was used to compare two different groups. In contrast, the One-Way ANOVA test was followed by Tukey's Post Hoc test for multiple comparisons. Statistical analysis was conducted using SPSS 16® (Statistical Package for Scientific Studies).

RESULTS

Contact angle (θº)

Independent t-test revealed that the Epoxidin Duo group showed (56.78 ± 0.68º) significantly higher values than the Well-Root ST group (53.25 ± 0.25º) as P < 0.05 and indicated in Table (2).

TABLE (2): Minimum, maximum, mean, and standard deviation of contact angle (θ°) in Well-Root ST and Epoxidin Duo groups.

N=10	Minimum (º)	Maximum (º)	Mean (º)	SD	P value
Well-Root ST	53.03	53.66	53.25	0.25	0.0001*
Epoxidin Duo	56.11	57.56	56.78	0.68	

SD: standard deviation.

**:Significant difference as P < 0.05.*

Dentinal tubules penetration

Independent t-test disclosed that the Well-Root ST group (10.40 ± 1.05 μm) revealed significantly overall higher values than the Epoxidin Duo group (7.61 ± 1.08 μm) as P < 0.05 and shown in Table (3).

One-Way ANOVA test revealed significant differences between all slices in both groups (P < 0.05). Tukey's Post Hoc test showed that coronal (12.05 ± 0.54 μm) (9.42 ± 1.56 μm) and middle (11.32 ± 1.26 μm) (8.67 ± 0.89 μm) slices in Well-Root ST and Epoxidin Duo groups, respectively, showed the highest mean values significantly, but with the non-significant difference between them.

While apical slices (7.85 ± 1.34 μm) (4.74 ± 0.78 μm) indicated significantly the lowest values in Well-Root ST and Epoxidin Duo groups, respectively, as shown in Table (3) and (Fig. 2 and 3).

TABLE (3): Mean and standard deviation of dentinal tubules penetration (µm) of Well-Root ST and Epoxidin Duo sealers in coronal, middle, and apical sections.

Groups N=14	Well-Root ST (μm)		Epoxidin Duo (μm)		P value
	M	SD	M	SD	
Coronal	12.05[a]	0.54	9.42[a]	1.56	<0.0001*
Middle	11.32[a]	1.26	8.67[a]	0.89	<0.0001*
Apical	7.85[b]	1.34	4.74[b]	0.78	<0.0001*
Overall	10.40	1.05	7.61	1.08	<0.0001*
P value	<0.0001*		<0.0001*		

Means with different superscript letters per column were significantly different as P < 0.05.
Means with the same superscript letters per column were insignificantly different as P < 0.05.
**Significant difference as P < 0.05.*

Push-out bond strength

Using an independent t-test, the Well-Root ST group (4.95 ± 1.05 MPa) denoted a significant increase in push-out bond strength than the Epoxidin Duo group (3.49 ± 0.24 MPa) in the coronal portion as P < 0.05. In contrast, it (1.54 ± 0.70 MPa) was significantly lower in the apical section than Epoxidin Duo (2.69 ± 0.42 MPa) as P < 0.05. However, both groups had a non-significant difference regarding middle slices and overall values, as revealed in Table 4.

The One-Way ANOVA test revealed a significant difference between all sections in both groups (P < 0.05). Further, Tukey's Post Hoc test revealed coronal (4.95 ± 1.05 MPa), and middle (3.65 ± 1.93 MPa) sections revealed significantly the highest values in the Well-Root ST group with the non-significant difference between them. In contrast, the significantly lowest values were recorded for apical slices (2.57 ± 0.85 MPa). In the Epoxidin Duo group, coronal slices (3.49 ± 0.24 MPa) were

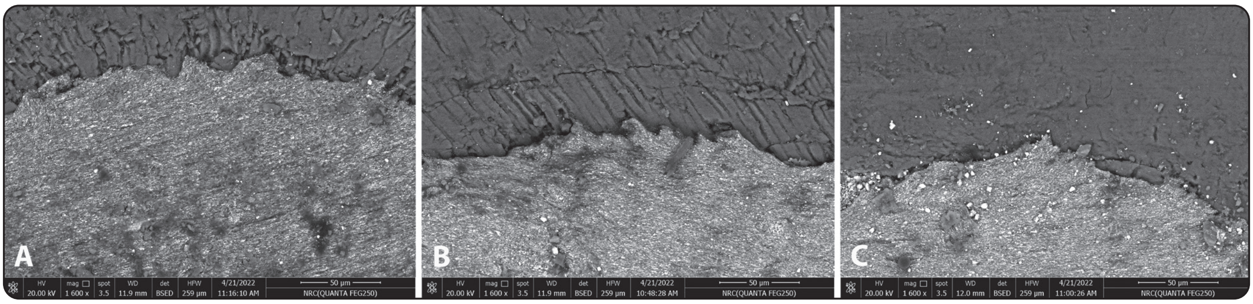

Fig. (2): Scanning electron microscope (SEM) images at 1600× magnification display dentinal tubule penetration of Well-Root ST sealer at different sections: A) Coronal, B) Middle, and C) Apical.

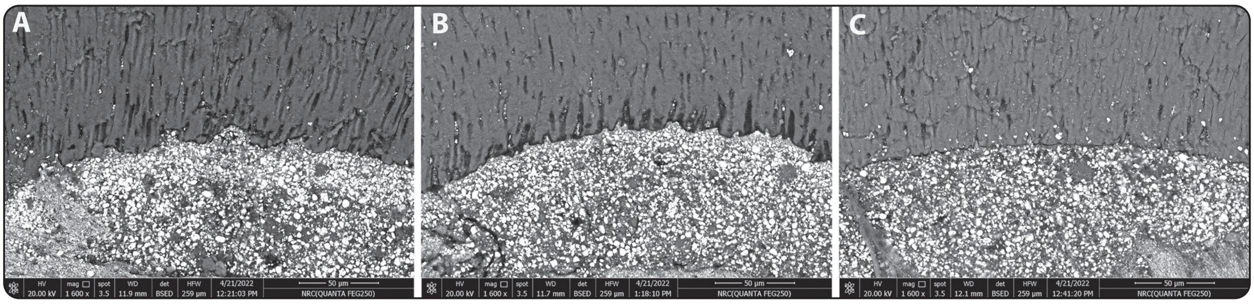

Fig. (3): Scanning electron microscope (SEM) images at 1600× magnification display dentinal tubule penetration of Epoxidin Duo sealer at different sections: A) Coronal, B) Middle, and C) Apical.

the significantly highest bond strength. The middle (2.57 ± 0.85 MPa) and apical (2.69 ± 0.42 MPa) slices showed the lowest values significantly, with a non-significant difference.

Mode of failure

In the Well-Root ST group, five specimens (50%) showed mixed failure mode between post, cement, and dentin. While 4 specimens (40%) exhibited an adhesive failure at the cement/dentin interface, and 1 specimen (10%) exhibited an adhesive failure at the post/cement interface, as shown in (Fig. 4). However, the Epoxidin Duo group showed an adhesive failure between cement and dentin failure in 5 specimens (50%), an adhesive failure between post and cement in1 specimen (10%), a mixed failure in 3 specimens (30%), and a cohesive failure within the cement in1 specimen (10%) as shown in (Fig. 5).

TABLE (4): Mean and standard deviation of push-out bond strength (MPa) in coronal, middle, and apical sections in Well-Root ST, Epoxidin Duo groups.

N=10	Well-Root ST (MPa)		Epoxidin Duo (MPa)		P value
	M	SD	M	SD	
Coronal	4.95[a]	1.05	3.49[a]	0.24	0.0004*
Middle	3.65[a]	1.93	2.57[b]	0.85	0.12
Apical	1.54[b]	0.70	2.69[b]	0.42	0.0003*
Overall	2.91	0.50	3.38	1.23	0.27
P value	<0.0001*		0.002*		

Means with the same superscript letters per column were insignificantly different as P > 0.05.
Means with different superscript letters per column were significantly different as P < 0.05.
**Significant difference as P < 0.05.*

TABLE (5): Failure modes of tested groups and their corresponding percentage.

Groups	N	Types of failure mode and %					
		Adhesive failure (%)		Mixed failure (%)	Cohesive failure(%)		
		Post/Cement	Cement/ Dentin	Post/Cement/ Dentin	Within Dentin	Within Cement	Within Post
Well-Root ST	10	1 - (10)	4 - (40)	5 - (50)	0 - (0)	0 - (0)	0 - (0)
Epoxidin Duo	10	1 - (10)	5 - (50)	3 - (30)	0 - (0)	1 - (10)	0 - (0)

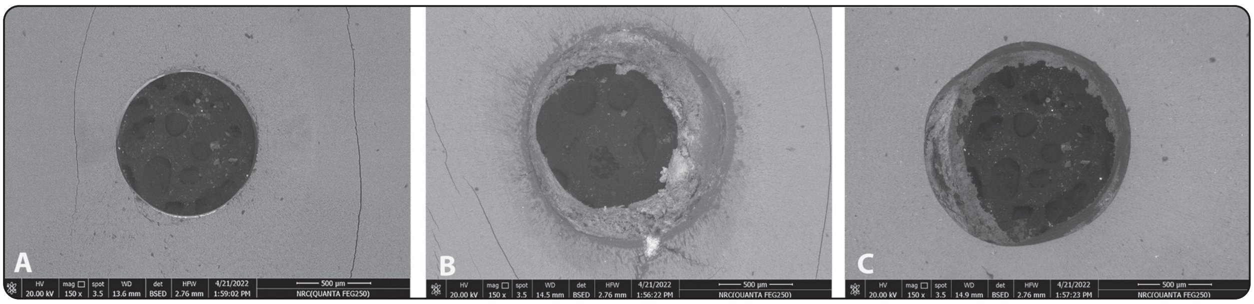

Fig. (4): Scanning electron microscope (SEM) images at 150× magnification showing the failure modes of the Well-Root ST sealer group: A) Adhesive failure at cement/dentin interface, B) Adhesive failure at post/cement interface, and C) Mixed failure.

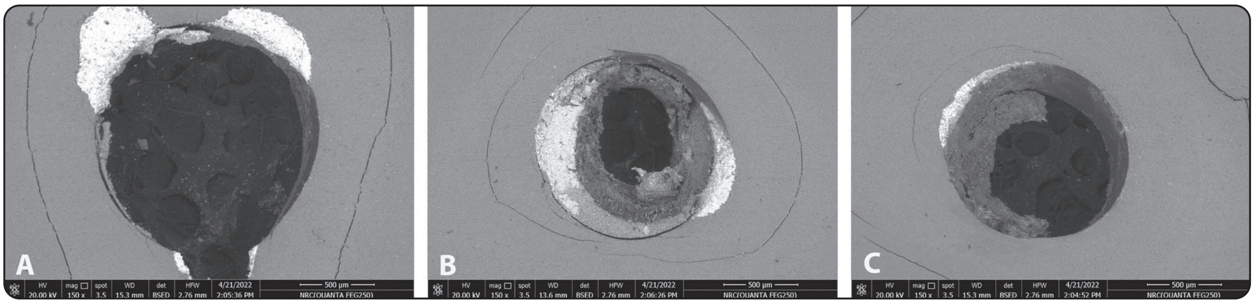

Fig. (5): Scanning electron microscope (SEM) images at 150× magnification showing the failure modes of the Epoxidin Duo sealer group: A) Adhesive failure at cement/dentin interface, B) Adhesive failure at post/cement interface, and C) Mixed failure.

DISCUSSION

Epoxy resin-based sealer showed excellent biocompatibility, minimal risk of postoperative inflammatory responses, and strong adhesion to root canal dentin; therefore, it is widely used as an obturation filling material for endodontically treated teeth.[5] Furthermore, calcium silicate-based sealers possess a treatment efficacy due to high hydraulic conductance, which tends to obstruct dentinal tubules.[24] In the presence of moisture, such as saliva, these biomaterials may stimulate mineralization at the dentine contact.[25,26] Therefore, both endodontic sealers were selected for the present study.

The endodontic sealing ability depends on penetration into dentinal tubules and mechanical interlocking of the sealer plug inside, forming a solid connection to preserve the sealer-dentin contact's integrity.[20] Therefore, it depends on smear layer removal, number and diameter of tubules, obturation technique acquired, and endodontic sealer flowability, which improve the sealer's infiltration and increase the bond strength to radicular dentin.[27,28] The influential factors for the sealer flow include temperature, setting time, and particle size.[29] Therefore, assessing the dentinal tubule penetration of sealers could reflect their potential sealing effect in filled root canals.

Several methods for evaluating the sealing ability of obturation materials have been proposed, including dye penetration, fluid filtration techniques, radioisotopes, scanning electron microscopy, electrochemical leakage tests, glucose penetration, and bacterial penetration test.[30] SEM was utilized in this study to precisely analyze the sealer's sealing capacity and adhesiveness to canal wall dentin or the sealer/gutta-percha interface in diverse root sections. Furthermore, it provides exceptional magnification, allowing more clear surface topography.[31] However, the technique is limited to the specimen's surface and can only expose a small proportion of all dentinal tubules of the root dentine; hence, specimen preparation, such as slicing, may influence the results because sealer may be washed out of the tubules.

Because of the simplicity of usage, the similar elastic modulus of dentin, enhanced translucency, and outstanding aesthetic qualities,[32] fiber posts are the preferred choice for restoring endodontically treated teeth with a massive loss of coronal structure. They have shown increasing resistance to root fracture and a highly relevant success factor for the longevity of future restoration of endodontically treated teeth.[33,34]

Post-space cleaning must be implemented regardless of the endodontic sealer used for canal obturation.[35] To ensure that the presence of the smear layer did not have positive or negative effects after post-space preparation, 17% EDTA and 5.25% NaOC1 irrigation solutions, respectively, were used to remove it. While this practice is generally recommended for removing the smear layer, the irrigation time was limited to 1 min to minimize the

EDTA destructive effect on the dentin's structure and ensure the efficacy of the smear layer irrigation.[36,37] Although the chemical nature of the irrigant utilized for post-space cleaning influences filling removal, the physical impact of sonic or ultra-sonic activation demonstrated improved bond strength.[38]

During fiber post-cementation, dual-cure resin cement ensures appropriate polymerization in the apical locations without light activation.[39] However, the self-cure process of dual-cure materials alone reduces cement hardness, polymerization rate, and bond strength.[32]

Despite the arguments favoring self-adhesive resin cements (SAC), some studies have shown lower push-out bond strength results than conventional dual-cured cements.[40,41] This is mostly owing to SAC's limited ability to hybridize dentin, which is currently regarded as the primary limitation and concern with these materials. SACs contain methacrylated phosphoric esters to dissolve the smear layer instead of phosphoric acid. However, these methacrylated phosphoric esters would be less efficient, especially in the presence of thick smear layers, and this could result in gaps between the surfaces, limiting adhesion.[40,41]

The current study investigated the effects of different types of root canal sealers on the bond strength to dentin after root restoration with fiber posts. The push-out bond strength test is frequently used to evaluate the filling system's dislodgment resistance.[22] It is a method considered a relevant prognostic factor to assess how well a root canal sealer adheres to the canal's wall and the core material.[42] For examining bond strength, the push-out test has the benefit of causing a consistent stress concentration and adhesive failure pattern on the specimens. The push-out, however, is not reliable as a sole guideline for decision-making by clinicians because it is primarily a laboratory test.[43]

The findings of this study partially approved the null hypothesis. Bioceramic sealers showed a lower contact angle and higher dentinal tubule penetration. However, both sealers showed a non-significant push-out bond strength difference.

In the current study, Well-Root ST sealer group recorded a lower contact angle (53.25 ± 0.25^{o}) than Epoxidin Duo sealer group (56.78 ± 0.68^{o}). Lower contact angle values imply that the substrate is well wet and has greater surface free energy than higher contact angle values.[44] Increased Epoxidin Duo sealer contact angle could be attributed to their chemical compositions and porosity differences.[45,46] Furthermore, including resin in Epoxidin Duo sealer can make this material hydrophobic with fewer pores. As a result, both bioceramic sealers have improved wettability and surface energy, which may affect their ability to adhere to dentin walls.[46] Several studies on bioceramic materials revealed non or low contact angle values.[45-47]

Overall, Well-Root ST dentinal tubule penetration recorded higher values (10.40 ± 1.05 μm) compared to the Epoxidin Duo (7.61 ± 1.08 μm). This could be referred to the alkaline nature of the sealer's byproducts may have denaturized the dentin collagen fibers, facilitating the sealer's penetration.[40] This disagreed with a study that found that Well-Root ST sealer exhibited significantly lower penetration depths than MTA Fillapex and AH26 sealers.[48]

In addition, the apical third showed the lowest dentinal tubule penetration values in Well-Root ST (7.85 ± 1.34 μm) and Epoxidin Duo (4.74 ± 0.78 μm) sealers compared to coronal and middle thirds. This could be explained by the dentin surface energy, which determines the degree of adhesion of sealers to the dentin wall, the surface tension and wettability of sealers, and the cleanliness of the dentin surface.[49] Dentin possesses various surface energies in the coronal, middle, and apical sections, which, combined with challenges encountered during the complete removal of the smear layer from the apical region due to the irregular structure and reduced density and diameter of dentinal tubules, maybe the trigger of its lower sealer penetration.[49-52]

Both endodontic sealers demonstrated greater bond strength in the cervical region of the post than in the apical region, as more dentinal tubules number, density, and diameter are marked.[53] In this study, the coronal (4.95 ± 1.05 MPa) and middle (3.65 ± 1.93 MPa) regions of Well-Root ST sealer had the highest mean push-out bond strength. These findings aligned with a study that found that the coronal and middle areas had much higher bond strengths than the apical ones.[21] Since light curing was used for the superficial cement layer, it was believed that the coronal region of the roots would have a higher degree of conversion and, as a result, a stronger bond strength.

The lowest bond strength in the apical region was recorded for both Well-Root ST (2.57 ± 0.85 MPa) and Epoxidin Duo (2.69 ± 0.42 MPa) sealers might be due to porous portions in the hybrid layer creating voids surrounding collagen fibrils, resulting in reduced bond strength and restricting the ability of self-adhesive resin cement to absorb tension caused by polymerization shrinkage.[54] The cavity configuration factor (C-factor) is connected to the ratio of adhesive to the free area, which is high in the root canal. It generates gaps at the adhesive interface between cement and post and cement and dentin, reducing bond strength and resulting in adhesive failures. Finally, the more apical; the space level, the more complex the control of the adhesive technique.[53] All these factors participate in adequate polymerization in post apical region.

The difficulties of completely removing all filling material at such deep thirds lead to leaving out sealer remnants.[21] As a result, adhesion with the intra-radicular dentin in this location is prevented by the dentinal tubules of the apical area, which are covered by a filling substance and serve as a mechanical barrier. This conclusion, however, conflicts with previous research that found no statistically significant difference in bond strength in different root thirds. The authors explained that finding by the less impact of tubule density on bond strength than the intertubular dentin surface area.[54]

In comparison to Epoxidin Duo sealer (3.49 ± 0.24 MPa), Well-Root ST sealer recorded a significant increase in push-out bond strength (4.95 ± 1.05 MPa) in the coronal portion ($P < 0.05$). This could be explained by the interaction of calcium silicate-based/bioceramic sealers with a phosphate-containing fluid produces a structure with the chemical and crystalline characteristics of both the tooth and the bone apatite. At the sealer-dentin interface, the apatite-produced deposits on collagen fibrils create an interfacial layer with tag-like structures leading to high bond strength.[55]

On the other hand, lower push-out bond strength in the coronal third in Epoxidin Duo sealer group could be due to root canal wall cleaning more efficiently, as sealer remnants can impact the adhesive interface and bond strength. They can obstruct dentinal tubules and reduce dentin's wettability, permeability, and reactivity affecting the adhesive bond strength.[56] As the Epoxidin Duo sealer was rigid and brittle, the force to produce a post-space caused the material to fracture into tiny pieces, breaking the connection at the interface where G-Cem relied primarily on micromechanical retention.[23] Also, due to the high contact angle's facilitation of removal and less sealer residue left on the canal walls, the dentinal tubule penetration is minimal. However, the adhesive strength of root dentin can be strengthened mainly by the affinity between epoxy-resin-based sealers and resin materials.[57]

However, Well-Root ST sealer was significantly lower (1.54 ± 0.70 MPa) in push-out bond strength in the apical section than Epoxidin Duo sealer (2.69 ± 0.42 MPa) as $P < 0.05$. This might be because bioceramic sealers negatively affect the bond strength of fiber posts as they come in contact with dentin. The calcium hydroxide in the sealers reacts with the phosphate ions to produce hydroxyapatite and tag-like structures, making removal of the sealer a challenge during post-space preparation.[23,51]

The current study showed a predominance of adhesive failure after the push-out test approved by SEM, with 50% at the cement/dentin interface in both tested groups and 10% at the cement/post interface. (Table 5 and Fig. 4 and 5). These findings were in accordance with previous studies.[43,58,59] This fact also reinforces that a strong bond was created between the fiber post and resin cement.

One of the study's limitations is that laboratory tests were performed under controlled conditions and should not be used to indicate or contraindicate clinical decisions. Furthermore, low intermittent loads and temperature variations (i.e., cyclic and thermocycling, respectively) could better imitate the function of endodontically treated teeth intraorally. Further studies are needed to investigate the effect of aging on specimens. Additionally, one obturation technique was applied. Only one type of bioceramic and epoxy resin-based sealers and self-adhesive resin cement were used during the study.

CONCLUSIONS

Bioceramic sealer showed higher wettability and dentinal tubule penetration than a resin-based sealer. However, both sealers affected the fiber post-bond strength at various regions throughout the root canal length without influencing the total bond strength.

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