ORIGINAL RESEARCH

Comparing Sectional and Total Dentin Bond Strengths of Three Endodontic Sealers after Using the Single-cone Obturation Technique: An *In Vitro* Study

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Abstract

Aim: This study aimed to investigate and compare the total and sectional bond strengths of three endodontic sealers when used with the single-cone obturation technique.

Materials and methods: Forty-five human maxillary central incisors were prepared and divided into three groups according to the type of endodontic sealer: Group I (Gutta-percha/AH Plus Jet), group II (Gutta-percha/GuttaFlow 2), and group III (RealSeal/RealSeal SE). All canals were filled with the single-cone technique. Roots were sectioned and scanning electron microscope (SEM) analysis was performed on randomly selected samples from each group to assess the root canal filling interfaces. A root section from each root level was subjected to a push-out test. The sectional and total bond strengths were analyzed, then the failure modes were investigated. Statistical analysis was performed using one-way analysis of variance (ANOVA) and Tukey's test, and alpha was set at 0.05.

Results: Significant differences in bond strength values were observed ($p < 0.05$), with RealSeal SE demonstrating the highest bond strength, particularly in the middle and apical root regions. On the contrary, GuttaFlow 2 exhibited the lowest bond strength. Cohesive failure modes were more common for AH Plus Jet and GuttaFlow 2, while RealSeal SE showed cohesive and adhesive failures. The SEM analysis revealed that each sealer exhibited different levels of adaptability to dentin and core material.

Conclusion: RealSeal SE and AH Plus Jet showed superior bond strength compared to GuttaFlow 2 when the single-cone obturation technique was used. The apical root sections exhibited the highest bond strength for all sealers, except for AH Plus Jet, which showed a higher bond strength in the coronal root sections.

Clinical significance: The current findings could guide dental professionals in choosing the most appropriate sealer for the single-cone obturation technique, potentially leading to more effective obturation procedures, especially for teeth requiring post and core restoration.

Keywords: AH Plus sealer, Dentin bond strength, GuttaFlow 2 sealer, RealSeal SE, Root canal obturation, Single cone obturation technique.

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Introduction

The success of endodontic treatment depends on the effectiveness of chemo-mechanical preparation and tight-seal obturation, which is essential to prevent canal infection and apical microleakage. Despite the effectiveness of contemporary obturation techniques, they cannot provide a full fluid-tight seal, require a significant amount of time, and require specialized equipment.[1] The popularity of the single-cone obturation technique can be attributed to the widespread availability of nickel–titanium (NiTi) rotary files and the corresponding gutta-percha cones.[2]

The choice of root canal sealer plays a significant role in the success of any obturation technique, particularly the single-cone technique.[3] The chemical composition of these sealers can influence their root canal sealing ability, affecting the overall success of the root canal filling procedure.[4] Consequently, the development of high-quality endodontic sealers is essential to minimize at least microbial leakage after endodontic treatment.

AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany) is an epoxy resin-based sealer that has excellent physicochemical properties and apical sealing ability; making it a popular choice for comparative studies.[5] RealSeal SE (SybronEndo, Orange, CA, USA) is a fourth-generation dual-cure self-etch methacrylate resin-based sealer that eliminates the need for separate etching and bonding steps, thus reducing the risk of errors.[6] RealSeal SE chemically bonds to radicular dentin and polymer-based core material such as Resilon (SybronEndo, Orange, CA, USA), creating a monoblock effect that enhances canal sealing and root strength.[7] Silicone-based sealers are also known for their superior sealing capabilities due to their setting expansion, insolubility, and flowability.[8] The GuttaFlow 2 (Coltène/Whaledent, Langenau, Germany), introduced in 2012 as a substitute for GuttaFlow, is a silicon-based sealer that includes gutta-percha powder, and nano-silver particles with a solubility of 0%, slight setting expansion, good flow and good adhesion to dentin.[9] Thus, it is recommended for the single-cone gutta-percha

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Conflict of interest: None

Table 1: Chemical composition of tested endodontic sealers

Type of sealer	*Delivery form*	*Composition*	*Manufacturer reference*
AH Plus Jet (Dentsply DeTrey GmbH, Konstanz, Germany)	Two-paste system	Epoxy resin, calcium tungstate, zirconium dioxide, aerosol, iron oxide, adamantine amine, N, N′-dibenzyl-5-oxa-non a diamine-1,9, coloring, TCD-Diamine, silicone oil	02CA60620115
GuttaFlow 2 (Coltène/Whaledent, Altstätten, Switzerland)	Two-paste system	Gutta-percha powder particles, polydimethylsiloxane, platinum catalyst, zirconium dioxide, micro-silver particles, coloring agent.	RO60013701
RealSeal SE (SybronEndo, Orange, CA, USA)	Two-paste system	Bisphenol glycidyl dimethacrylate (BISGMA), urethane dimethacrylate (UDMA), polyethylene glycol dimethacrylate (PEGDMA), ethoxylated bisphenol-A dimethacrylate (EBPADMA), barium sulfate, barium borosilicate glass, silica, calcium hydroxide, bismuth oxychloride with amines, aluminum oxides	SY9722006

obturation technique.[9] However, dental professionals could face challenges in understanding how the composition of sealers affects their bond strength to radicular dentin, which could impact the success of endodontic treatment. The quality of bonding between endodontic sealers and radicular dentin is critical to maintaining the integrity of the root canal seal. The push-out test is a commonly used method to evaluate this bond strength.[10] Therefore, using this test to assess the performance of root canal sealers in the single-cone obturation technique could provide valuable information to make informed decisions that lead to better long-term clinical outcomes.

This study aimed to evaluate the dentine bond strength of three different endodontic sealers used with the single-cone obturation technique: Epoxy-based resin, methacrylate resin, and silicon/gutta-percha powder-based sealers. Essentially, this study seeks to determine whether variations in sealer chemical composition result in significant differences in dentin bond strength values.

The null hypothesis of the study suggested that there were no significant differences between the total and sectional bond strengths of the experimental sealers. The practical implications of these findings could guide dental professionals in choosing the most appropriate sealers, potentially leading to more effective obturation procedures.

Materials and Methods

Samples Selection and Preparation

This study was conducted during the period between 2021 and 2023, following approval from the local Research Ethics Committee (Reg. No.: D-H-S-2020-OCT-15-2). The selection criteria for teeth included those with sound, straight roots with closely matched anatomical dimensions, and a minimum root length of 15 mm. Teeth with open root apexes, root cracks, root resorption, or wide, irregular canals were excluded from the study.

Following a pilot study, the sample size was determined using G*Power software version 3.19.7 (Heinrich-Heine-Universität, Düsseldorf, Germany) (Power = 0.8; effect size = 0.25; level of significance = 0.05; the number of groups = 3; standard deviation = 7); accordingly, the smallest sample size per group was set at 39 root sections (13 teeth). However, to ensure a powerful statistical analysis, a total of 45 root sections (15 teeth) were used for each group.

After selecting the teeth, their crowns were cut at the cementoenamel junction using a low-speed, double-sided diamond disc (Komet, USA) and under a water coolant provided that the root length was maintained at 15 mm. Root canals were prepared using ProTaper Universal NiTi rotary files (Dentsply Maillefer, Ballaigues, Switzerland) up to size F4 (40/0.06) after determining the working length. Throughout the instrumentation process, each file's use was followed by irrigation with 1 ml of 3% sodium hypochlorite (NaOCl) solution (Sigma-Aldrich, St. Louis, MO, USA), followed by 1 ml of 17% ethylenediaminetetraacetic acid (EDTA) (MD-Cleanser, Meta Biomed Co. Ltd., Korea) to facilitate the removal of the smear layer.

The prepared samples were randomly assigned to three experimental groups, each consisting of 15 prepared roots using a randomizer software program (https://www.randomizer.org/). The root canals were filled using the following combinations: Group I with AH Plus Jet/Gutta-percha, Group II with GuttaFlow 2/Gutta-percha, and Group III with RealSeal SE/Resilon. The chemical composition of each sealer is detailed in Table 1.

Filling of the Root Canals

Each root was centrally embedded in a specially manufactured metal mold, which was subsequently filled with cold chemical cure acrylic resin (DPI RR Cold Cure, Bombay Trading Corporation Ltd., India). The prepared canals were dried and ProTaper F4 gutta-percha points were selected as master cones to fill the canals in the first and second groups, while RealSeal points (40/0.06) were used for the third group.

To complete the obturation process, all sealers were thoroughly mixed following the manufacturer's instructions and placed into root canals using a #30 Lentulo Spiral (Dentsply, Maillefer). The single-cone obturation technique was used to fill all canals. The coronal excess of filling materials was removed using a heated instrument and the excess sealer was removed using a piece of cotton moistened with alcohol. In the third group, RealSeal SE (SybronEndo, Orange, CA, USA) was light-cured for 40 seconds using a light-emitting diode device (Lite 696, Dentamerica, USA). All samples were radiographically evaluated to verify the completeness of the canal filling. Subsequently, they were placed in an incubator set at 37°C with 100% humidity for one week to confirm the full setting of all sealers.

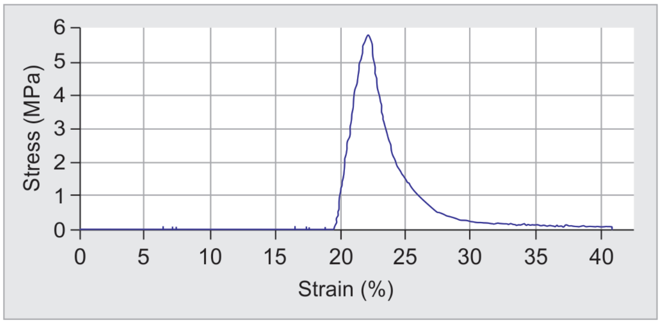


Fig. 1: Stress–strain curve for a selected sample showed a sudden drop in the applied force indicating failure

Preparation of Root Sections

Each filled root was horizontally sectioned into 1 mm thick slices using a precision cutting machine (IsoMet, Buehler, Lake Bluff, IL, USA). One slice from each third of the root was randomly designated for the push-out test. Therefore, three root sections were obtained from each root with a total of 45 root sections per each group were subjected to push-out test.

The thickness of each root section was measured using a digital caliper with a precision of 1 µm. The apical aspect of each slice was marked with a waterproof pencil to ensure proper orientation during the push-out test. Under a digital stereomicroscope (Leica EZ4W, Germany) at a magnification of 35×, each slice was inspected both apically and coronally, and photographic records were made. It was expected that all canals would exhibit a circular cross-section with no visible voids in the filled area. The apical and coronal diameters of the filled canals were measured using ImageJ software (National Institutes of Health, MD, USA). Flat-ended stainless-steel plungers with tip diameters ranging from 0.4 to 1.00 mm were manufactured for the application of force to the filling material.

Mechanical Testing

The push-out test was conducted according to a previously established protocol.[4] The plunger was carefully positioned to cover approximately 85% of the filling area without contacting the dentin. Using a universal testing machine (Testometric Company Ltd., UK), a compressive load was applied in the apical coronal direction at a continuous load rate of 0.5 mm/minute. The test continued until a sudden and marked drop in the applied force was observed on the stress/strain curve, indicating bond failure (Fig. 1).

The maximum force required to dislodge the filling material was recorded in Newtons (N). The bond strength, measured in megapascals (MPa), was calculated using the following formula: $F/LS\sqrt{(Ed/Ef)}$, where F represents the dislodging force (Newton), LS denotes the lateral surface area (mm^2), Ed is the modulus of elasticity of dentin (16,000 MPa), and Ef represents the modulus of elasticity of the respective filling material, either Resilon (86.58 MPa) or gutta-percha (100 MPa).[11–13] The lateral surface area was calculated using the formula:[14] $LS = \pi (R_1 + R_2)\sqrt{(R_1 - R_2)^2 + H^2}$, where $\pi = 3.14$; R_1 is the radius of the canal on the coronal side (mm), R_2 is the radius of the canal on the apical side (mm), and H is the thickness of the root section (mm). Sectional bond strength (coronal, middle, and apical) and total push-out bond strength values were calculated and recorded for all experimental groups.

Assessment of Failure Modes

After the push-out test, the root sections were examined under a stereomicroscope (Leica EZ4W, Germany), with two independent assessors blinded to the experimental conditions. This examination was designed to identify the specific failure mode resulting from the dislodgment of the filling materials. The Selzer classification method[4] was used to assess the failure mode, categorizing it as an adhesive when less than 25% of the dentinal walls were coated with a sealer, cohesive when more than 75% of the dentinal walls were coated with a sealer, or mixed when the coverage fell within the range of 25–75% of the dentinal walls (Fig. 2).

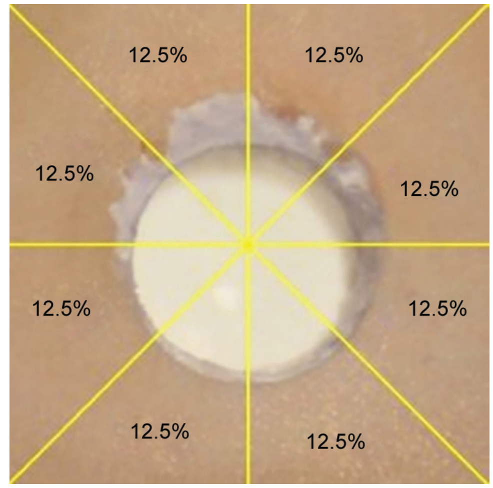


Fig. 2: Cohesive failure in a selected sample according to Selzer's criteria as more than 75% of root canal surface coated by sealer

Scanning Electron Microscope Analysis

Before initiating the push-out test, three samples were randomly selected from each group for scanning electron microscope (SEM) analysis. These samples were subjected to a detailed process that included drying, gold sputter coating, and scanning. The SEM examinations were carried out using the TSCAN VEGA3 SEM (TSCAN Corporation, Kohoutovice, Czech Republic) at an acceleration voltage of 15 kV. Sequential SEM photomicrographs were captured at magnifications ranging from 200× to 1500× to facilitate a comprehensive evaluation of the dentin-sealer-core interfaces. Each photomicrograph was assessed by two independent evaluations.

Statistical Analysis

All statistical analyses were performed using the IBM SPSS version 20 software program (IBM, Armonk, NY, USA). To assess the sectional and total push-out bond strengths, one-way analysis of variance (ANOVA) and Tukey tests were used. Statistical significance was set at $p < 0.05$. Furthermore, the frequencies of the failure modes were calculated and presented in tabular format.

Results

Table 2 displays total and sectional push-out bond strengths (MPa) for all groups. The one-way ANOVA test revealed significant differences in total bond strengths between the groups ($p < 0.05$). The third group (RealSeal SE) had the highest total bond strength (21.56 MPa), which was not significantly different from the first group (AH Plus Jet, 17.72 MPa), but was significantly higher than the second group (GuttaFlow 2, 14.19 MPa).

In terms of coronal bond strength, the first group (AH Plus Jet) demonstrated significantly a higher mean value (19.85 MPa) compared to the second and third groups (14.35 MPa and 13.61 MPa,

Table 2: Statistical results of sectional and total push-out bond strengths of all groups

Groups	*Sectional push-out bond strengths ($\bar{x} \pm SD$, MPa)*				*Total push-out bond strengths ($\bar{x} \pm SD$, MPa)*
	Coronal	*Middle*	*Apical*	*ANOVA (p-value)*	
Group I (AH Plus Jet)	19.86 ± 4.19^{A1}	14.99 ± 2.35^{A2}	18.32 ± 4.86^{A12}	0.005	17.72 ± 4.37^{AB}
Group II (GuttaFlow 2)	14.35 ± 2.88^{B1}	14.60 ± 2.49^{A1}	21.77 ± 3.55^{AB2}	0.000	14.19 ± 2.69^{B}
Group III (RealSeal SE)	13.61 ± 2.76^{B1}	23.47 ± 1.60^{B2}	24.59 ± 3.72^{B2}	0.000	20.56 ± 5.70^{A}
ANOVA (*p*-value)	0.000	0.000	0.001		0.000

$\bar{x}$, mean; *SD*, standard deviation; MPa, megapascal
Different superscript letters in each column and superscript numbers in each row had significant differences ($p < 0.05$)

respectively). The third group (RealSeal SE) showed significantly higher mean values of middle and apical bond strength (23.47 and 24.59 MPa, respectively) compared to other groups. The apical bond strengths in all groups were significantly higher than the middle and coronal bond strengths, except for the first group, which had superior coronal bond strength. No significant differences were observed between the apical and coronal bond strengths in the first group.

Table 3 presents the distribution of failure modes, with the first and second groups predominantly experiencing cohesive failure (90%), while adhesive failure was more common in the third group (53.3%). Cohesive failure was also significant in the third group (40%).

The SEM examination showed variable gaps and seals at the sealer-dentin-core interfaces (Figs 3 to 5). AH Plus sealer showed better adaptation with the dentinal walls and core materials in the coronal root sections compared to the apical and middle root sections (Fig. 3). Conversely, GuttaFlow 2 exhibited a higher incidence of gaps at core-sealer and dentin-sealer interfaces, with these gaps predominantly occurring at the core-sealer interface, particularly in the coronal and middle root thirds (Fig. 4). However, GuttaFlow 2 showed better adaptation to dentin and core in the apical root section. The RealSeal SE showed poor adaptation to core material especially in coronal root sections, where there was a good adaptation with the dentin and core material in the apical and middle root sections (Fig. 5). Additionally, RealSeal SE achieved a deeper penetration into dentinal tubules in all root levels than GuttaFlow 2 and AH Plus Jet.

Discussion

This study aimed to compare the total and sectional bond strength of three endodontic sealers (AH Plus Jet, GuttaFlow 2, and RealSeal SE) with radicular dentin when using the single-cone obturation technique. The results showed significant differences in bond strength values among the tested sealers, therefore the null hypothesis was rejected.

The correction factor recommended by Chen et al.[11] was applied during bond strength calculations. This adjustment was necessary due to the significantly lower modulus elasticity of Resilon (86.58 MPa) and gutta-percha (100 MPa) compared to dentin (16,000 MPa).[12,13] The thickness of each root section was consistent with the guideline provided by Chen et al.,[11] who commended a thickness greater than 60% of the filled canal diameter to ensure no impact on the push-out bond strength. The thickness of all root sections was 1 mm, with canal diameters ranging from 0.5 to 1.16 mm. The plunger tips were intentionally sized about 0.85 times smaller than the canal diameter to avoid contact with the root dentin during the test.[14,15]

Table 3: Distribution of failure mode (%) after dislodgment of tested filling materials

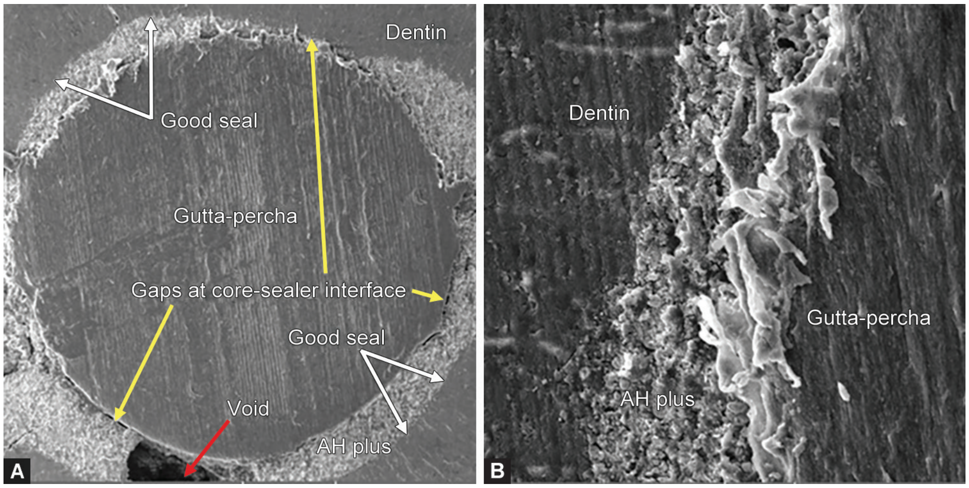
Groups	*Total failure modes (%)*		
	Adhesive (%)	*Cohesive (%)*	*Mixed (%)*
Group I (AH Plus Jet)	3.3	90	6.7
Group II (GuttaFlow 2)	6.7	90	3.3
Group III (RealSeal SE)	53.3	40	6.7

RealSeal SE and AH Plus Jet demonstrated significantly higher total push-out bond strength values compared to GuttaFlow 2. The reduced bond strength of GuttaFlow 2 could be attributed to the presence of tiny voids resulting from a high sealer-to-gutta-percha ratio in the single-cone obturation technique and lower contact angles affecting its dentin wettability due to the presence of silicon oil in its composition.[16,17] This finding agrees with Bhandi's findings.[18]

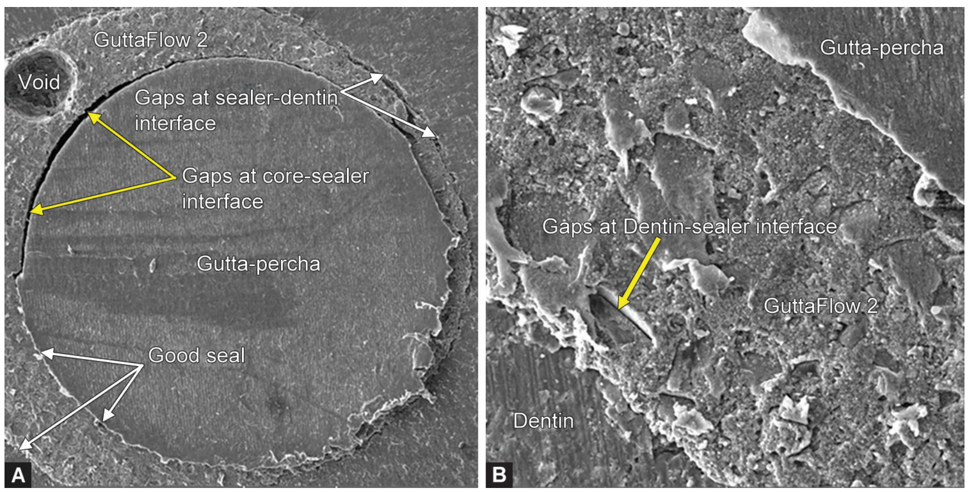
Regarding sectional bond strength, significant differences were observed among the sealers tested, consistent with Carneiro et al.[19] Generally, bond strength values were greater in the apical root sections, except for AH Plus Jet, which showed superior bond strength in the coronal region. This could be related to the presence of larger coronal dentinal tubules.[19] RealSeal SE outperformed both in the middle and apical sections, congruent with Pawińska et al.[20] and Skidmore et al.,[21] but in contrast to Chandarani et al.[22] This discrepancy might be due to the methodologies used. Furthermore, RealSeal SE exhibited stronger bonding to the middle and apical radicular dentin than the coronal region. This difference can be attributed to the higher density of dentinal tubules in these areas and the slower setting time of the sealer.[23,24] The weaker bond strength of RealSeal SE in coronal radicular dentin could be linked to polymerization shrinkage during coronal photopolymerization.[14]

GuttaFlow 2 demonstrated apical bond strength comparable to AH Plus Jet and RealSeal SE, in line with Bouillaguet et al.[25] This similarity can be attributed to the low viscosity, pseudoplasticity, and setting expansion of GuttaFlow 2.[26] However, these results contrast with the findings of Adhikari and Jain,[26] which favored GuttaFlow in apical adaptation. In the middle root sections, GuttaFlow 2 and AH Plus Jet showed comparable bond strengths, though lower than RealSeal SE. In the coronal region, GuttaFlow 2 and RealSeal SE displayed similar results, which were significantly lower bond strengths than AH Plus Jet, likely due to the suboptimal adaptation of GuttaFlow 2.[24]

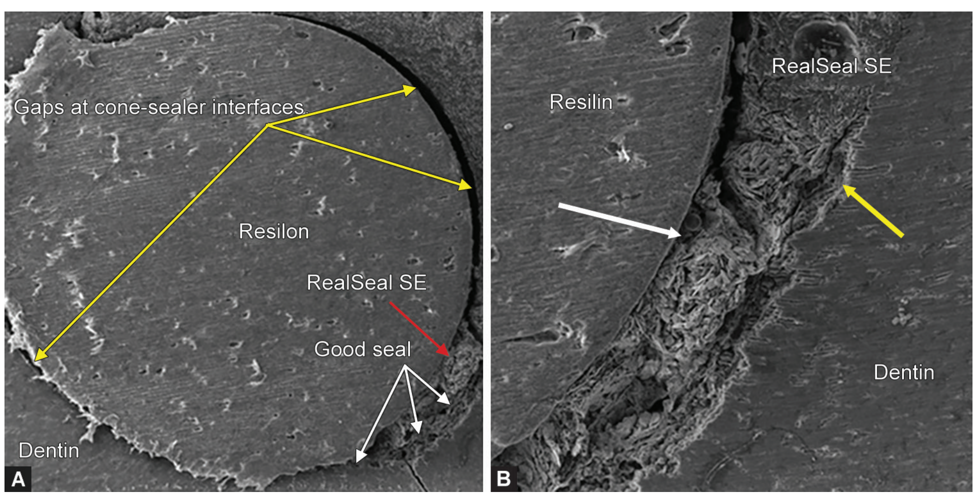
Cohesive failure modes were predominant in both AH Plus Jet and GuttaFlow 2, indicating their superior bonding to dentin compared to Gutta-percha in the single-cone obturation technique.[27] RealSeal SE showed high percentages of adhesive



Figs 3A and B: Scanning electron microscope images illustrating interfaces between gutta-percha, AH Plus Jet, and dentin: (A) Lower magnification image (200×) showing a good seal between the sealer and dentin (white arrows), a void within the sealer layer (red arrow), and multiple gaps between the sealer and gutta-percha (yellow arrows); (B) Higher magnification image (1500×) demonstrating a secure seal at the dentin-sealer-gutta-percha interface



Figs 4A and B: Scanning electron microscope images illustrating interfaces between gutta-percha, GuttaFlow 2, and dentin: (A) Low-magnification image (200×) showing multiple gaps at sealer-dentin-gutta-percha interfaces (yellow arrows), a prominent void within the sealer layer, and some areas with a secure seal at sealer-dentin-gutta-percha interfaces (white arrows); (B) Higher-magnification image (1000×) revealing an interfacial gap between GuttaFlow 2 and dentin (yellow arrow)



Figs 5A and B: Scanning electron microscope images illustrating interfaces between Resilon, RealSeal SE, and dentin: (A) Low-magnification image (200×) showing multiple gaps at Resilon-RealSeal SE interfaces (yellow arrows) and a secure seal at the sealer-dentin interfaces (white arrows); (B) High-magnification image (500×) demonstrating an excellent seal at the dentin-sealer interface and a gap at the Resilon-sealer interface (yellow arrow) and cohesive failure modes, which is consistent with the findings of Carneiro et al.[19] The cohesive failure mode of AH Plus Jet may be attributed to its stronger bond to both dentin and gutta-percha.[28] The cohesive failure of GuttaFlow 2 might be due to better adhesion to dentin than gutta-percha, supported by the study's results.

Scanning electron microscope evaluations revealed that AH Plus Jet adapted excellently to dentin walls but with shallow penetration into dentinal tubules and multiple tiny gaps at the sealer-core interface. GuttaFlow 2 displayed numerous wide gaps at the sealer-dentin and sealer-core interfaces, along with large voids within the sealers. RealSeal SE, on the other hand, exhibited excellent adaptation to dentin walls with deeper penetration into the dentinal tubules. These findings were consistent with Jain and Adhikari and supported by the current results of the push-out test.[29] The penetration of sealer into the dentinal tubules enhances radicular sealing by increasing the contact areas between dentin and filling materials. However, some authors suggested that the force required to dislodge the filling materials from the root canals is independent of the depth penetration of sealer into dentinal tubules.[30] Based on the results of this study, it is recommended to use the RealSeal SE obturation system when the post and core restoration is planned, as this system had the highest bond strength in the apical and middle root sections.

Although informative, this study has some inherent limitations, such as variations in moisture levels within dentinal tubules, the lack of strict standardization in sealer application, and a focus that does not encompass voids within the sealers. The absence of SEM analysis on samples following the push-out test could be seen as a limitation, as this analysis could provide valuable insights into the failure mode. Future research should also explore innovative techniques and materials aimed at minimizing potential void formation within sealers and enhancing their adaptability in different regions of the root canal. Additionally, investigating the influence of variables such as sealer application volume and moisture control on bond strength could further contribute to improving the clinical performance of endodontic sealers.

Conclusion

Within the limitations of the current study, the overall bond strength of RealSeal SE and AH Plus Jet outperformed GuttaFlow 2 when the single-cone obturation technique was used. However, Realseal SE exhibited superior bond strength in the apical and middle root thirds, while AH Plus Jet had the greatest bond strength in the coronal root thirds.

Clinical Significance

These findings emphasize the importance of sealer composition and root canal level in determining bond strength and failure modes, providing valuable insights for future research in endodontics and clinical practice. Considering the present findings, RealSeal SE could be the most suitable option for teeth requiring post and core restorations.

Acknowledgment

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Author Contributions

Mohamed Elsayed (author) designed the work and critically reviewed the manuscript and approved the final version, performed the laboratory work, analyzed the data, and critically reviewed the manuscript. The author approved the final manuscript and is accountable for all aspects of the work, in ensuring questions related to the accuracy or integrity of any parts of the work are appropriately investigated and resolved. The author has read and agreed to the published version of the manuscript.

Data Availability Statement

The data used to support the findings of this study will be available from Dr Mohamed Elsayed at this email: elsayednada@yahoo.com for the researchers who meet the criteria for accessing this data. The data can be requested after the publication of this article. However, requests for the data, [6/12 months] after the publication of this article, will be considered by the corresponding authors.

Ethics

Local Research Ethics Committee (RD-2014/15-23).

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