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PUSH-OUT BOND STRENGTH OF ZIRCONIA POSTS WITH DIFFERENT LUTING AGENTS: AN IN VITRO COMPARISON

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ABSTRACT

Background: Zirconia posts are widely used due to their strength, biocompatibility, and esthetics, but their inert polycrystalline surface complicates bonding. Selecting an appropriate luting agent is therefore essential. **Aim:** This study compared the push-out bond strength of zirconia posts cemented with bulk-fill resin composite (BF), resin-modified glass ionomer cement (RMGIC), and self-adhesive resin cement (SARC) across cervical, middle, and apical root regions. **Materials and Methods:** Thirty extracted single-rooted premolars were endodontically treated, decoronated, and prepared for zirconia post placement. Specimens were divided into three groups ($n = 10$) according to the luting agent used. Following cementation, roots were sectioned into 2-mm slices and subjected to push-out testing with a universal testing machine. Data were analyzed using two-way ANOVA and Tukey's post hoc test ($\alpha = 0.05$). **Results:** Bond strength was significantly influenced by both luting agent and root region ($p < 0.05$). BF achieved the highest values (**cervical: 27.67 ± 1.20 MPa; middle: 20.78 ± 1.20 MPa; apical: 13.83 ± 1.20 MPa**), followed by RMGIC, while SARC consistently showed the lowest performance (**apical: 12.66 ± 1.20 MPa**). Cervical regions outperformed middle and apical thirds ($p < 0.001$). Failure analysis indicated predominantly cohesive failures with BF (67%) and adhesive failures with SARC (50%). **Conclusion:** Bulk-fill resin composites provide superior retention for zirconia posts compared with RMGIC and SARC, with cervical dentin offering the most favorable bonding substrate. Clinically, BF cements appear to be the most reliable choice, while SARC should be avoided.

KEYWORDS: Zirconia posts; Push-out bond strength; Bulk-fill resin composite; Resin-modified glass ionomer; Self-adhesive resin cement.

INTRODUCTION

The restoration of endodontically treated teeth frequently necessitates the placement of intraradicular posts to reinforce coronal restorations and provide long-term retention and stability. Among the available options, zirconia posts have gained widespread acceptance owing to their superior esthetic qualities, high flexural strength, and biocompatibility, attributes that are particularly advantageous in the anterior region where translucency and mechanical durability are equally critical (Li et al., 2024). However, despite these advantages, achieving durable adhesion to zirconia remains a clinical challenge. In contrast to glass fiber posts, which facilitate micromechanical and chemical interaction with resin-based cements, zirconia is a non-silica, polycrystalline ceramic with an inert surface that resists conventional silanization. Consequently, the use of traditional silane coupling agents is ineffective, resulting in compromised long-term bonding (Rigos et al., 2023; Su et al., 2025).

The choice of luting agent thus becomes a decisive factor in determining the clinical success of zirconia post restorations. Bulk-fill (BF) resin composites have been introduced as innovative restorative materials designed to reduce polymerization shrinkage stress, increase depth of cure, and simplify placement techniques, thereby potentially improving adaptation to radicular dentin (Al-Aali et al., 2022). Resin-modified glass ionomer cements (RMGIC), while offering chemical adhesion to dentin and the added benefit of fluoride release, remain vulnerable to hydrolytic degradation and generally present lower bond strengths compared with resin systems, limiting their long-term performance in high-stress environments (Efe and Güçlü, 2021). By contrast, self-adhesive resin cements (SARC) simplify the clinical procedure by eliminating etching and priming steps and rely on functional acidic monomers to bond directly with hydroxyapatite; nonetheless, their bonding capacity to both zirconia and radicular dentin is consistently reported to be inferior when compared with multi-step resin-based systems (Attia and Kern, 2011).

Bond strength is also strongly influenced by the anatomical root region. Cervical slices often provide higher retention values due to greater dentin tubule density, improved access for cement placement, and enhanced light transmission that favors polymerization, whereas middle and apical regions are typically associated with reduced adhesive effectiveness (Goracci and Ferrari, 2011). Moreover, studies simulating intraoral conditions through thermocycling and artificial aging confirm that the durability of the adhesive interface is further compromised over time, underscoring the importance of selecting luting agents capable of maintaining stable adhesion under functional stresses (Namdari et al., 2020; Dachev et al., 2025).

Furthermore, Recent research highlights the importance of functional monomers such as **10-MDP**, which establish chemical bonds with zirconia surfaces, along with surface conditioning techniques like airborne particle abrasion and silica coating that enhance micromechanical interlocking and surface wettability both of which enhance micromechanical interlocking and wettability of zirconia surfaces (Kern, 2015; Li et al., 2024). These considerations highlight the clinical need for systematic evaluations of different luting agents to identify the most effective approach for achieving durable bonding with zirconia posts.

Accordingly, the current investigation sought to evaluate and compare the push-out bond strength of zirconia posts luted with bulk-fill resin composite, resin-modified glass ionomer cement, and self-adhesive resin cement in the cervical, middle, and apical thirds of root canal dentin. The null hypotheses tested were that there would be no significant difference in push-out bond strength among the three luting agents and that the anatomical root region would not significantly affect bonding performance.

Despite numerous in vitro investigations, clinical evidence remains limited regarding the long-term retention of zirconia posts under functional stresses such as cyclic mastication, thermomechanical aging, and intraoral humidity. These factors significantly compromise the adhesive interface and may lead to early debonding in clinical scenarios. Therefore, it is essential to integrate laboratory findings with long-term clinical trials, as only in vivo studies can validate whether laboratory bond strength values translate into durable and predictable retention outcomes in daily dental practice (Ehlers et al., 2020; Beketova et al., 2023).

MATERIALS AND METHODS

Sample Selection and Preparation

This in vitro experimental investigation was conducted on **thirty freshly extracted mandibular second premolars**, chosen to ensure standardization of morphology and dentin substrate. The inclusion criteria specified single, straight roots of comparable diameter, free from caries, cracks, resorption, or other developmental anomalies. Teeth were obtained from individuals aged between **18 and 24 years** who had undergone extractions for orthodontic purposes, and **informed consent** was secured prior to sample collection. The average root length was approximately **16 mm**, and following extraction, specimens were cleaned of calculus deposits, disinfected in **5.25% sodium hypochlorite for 10 minutes**, and stored in distilled water at **37 °C for 24 hours** to maintain hydration and simulate intraoral conditions (Şenel et al., 2025).

Fig(1): length of the root used in the study.

Endodontic Treatment

To ensure uniformityAll specimens were sectioned at the cementoenamel junction using a water-cooled diamond disc, leaving a standardized root length of **15 mm**. Root canal instrumentation was carried out using **rotary NiTi files up to size #40 with a 0.06 taper**, consistent with prior methodologies (Goracci and Ferrari, 2011). Irrigation involved Irrigation was performed with alternating rinses of 2.5% sodium hypochlorite and 17% EDTA to remove the smear layer (Attia and Kern, 2011). After instrumentation, the canals were dried with sterile paper points and filled with gutta-percha and a resin-based sealer using the lateral condensation technique. The specimens were then stored at 37°C in 100% humidity for one week to allow complete sealer setting (Li et al., 2024).

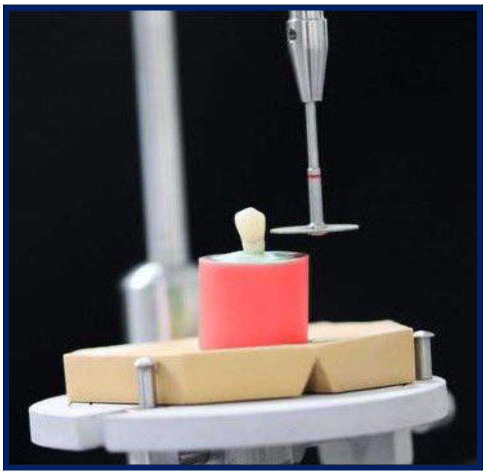

Fig (2): **sectioning of the crown using dental surveyor.**

Post Space Preparation

Post spaces were prepared by removing gutta-percha to a standardized depth of **10 mm**, while preserving at least **4 mm of apical seal** in accordance with established post-endodontic restorative protocols (Rigos et al., 2023). Preparations were achieved using the calibrated drills provided by the zirconia post manufacturer. The canal walls were subsequently rinsed with distilled water and dried with sterile paper points prior to cementation.

Fig (3): Root canal treatment using survey.

Experimental Grouping and Cementation

The sample were randomly assigned into **three experimental groups** (n = 10 each) according to the luting agent used:

- **Group 1 (Zir + BF):** Zirconia posts luted with bulk-fill resin composite.
- **Group 2 (Zir + RMGIC):** Zirconia posts luted with resin-modified glass ionomer cement.
- **Group 3 (Zir + SARC):** Zirconia posts luted with self-adhesive resin cement.

Prefabricated zirconia posts of standardized dimensions were cleaned with alcohol before cementation. All luting agents were manipulated according to **manufacturers' instructions**. Posts were seated using finger pressure, and excess cement was carefully removed. For resin-based groups, polymerization was performed with an **LED curing unit (1200 mW/cm²) for 40 seconds per surface**, as recommended in prior resin bonding studies (Su et al., 2025). Following cementation, all specimens were stored in distilled water at **37 °C for 24 hours** (Beketova et al., 2023).

Sectioning of Specimens

Each root was horizontally sectioned into **2-mm-thick slices** using a low-speed diamond saw under continuous water cooling. Slices represented the **cervical, middle, and apical thirds** of the root canal, a methodology widely applied in push-out bond strength evaluations (Attia and Kern, 2011; Al-Aali et al., 2022). Each slice was coded and prepared for subsequent testing.

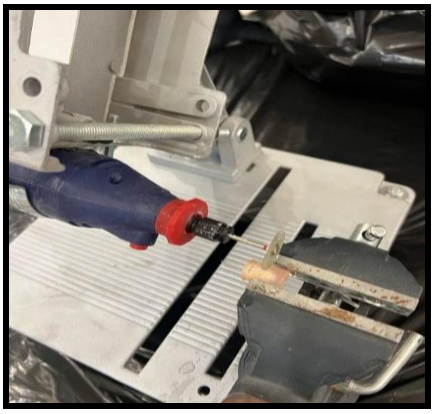

Fig (5): Sectioning of root slices into cervical, middle, and apical thirds.

Push-Out Bond Strength Test

For mechanical testing, each sample was mounted in a **customized metal jig** and loaded in a **universal testing machine** (manufacturer, city, country to be specified). A cylindrical plunger, slightly smaller than the canal diameter, applied a load at a crosshead speed of **0.5 mm/min** until post dislodgment occurred. The **maximum load (N)** was recorded and converted into **bond strength (MPa)** according to the standard formula (Kern, 2015).

Bond Strength (MPa)=Bonded Area (mm2)

Load at Failure (N)

The bonded area (A) was calculated using the following geometric formula:

A=π(R+r)(R−r)2+h2

Were:

- R = coronal radius,
- r = apical radius,
- h = slice thickness (2 mm).

To ensure methodological transparency, the universal testing machine model (e.g., Instron 3345, Instron Corp., Norwood, MA, USA) should be specified, together with calibration status and software version used for data acquisition. Similarly, the commercial brand names, manufacturers, and countries of origin of all luting agents (bulk-fill composite, RMGIC, and SARC) should be reported to facilitate reproducibility and enable meaningful comparison with **other investigations.**

Fig (7): universal testing machine slices.

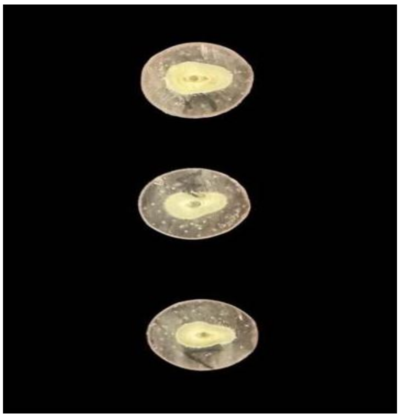

Fig (8): coronal, middle, and apical slices.

Fig (9): applying forces to the slices.

Failure Mode Analysis

Post-testing, specimens were examined under a **stereomicroscope at ×25 magnification**, and failure modes were classified as.

1. Adhesive failure (between cement and dentin or cement and post),
2. Cohesive failure (within the cement itself),
3. Mixed failure (a combination of adhesive and cohesive).

This classification followed the criteria described in earlier retention studies (Goracci and Ferrari, 2011; Li et al., 2024).

(a)adhesive failure **(B) cohesive failure** **(c) Mixed failure**

Fig (10): Failure modes in push-out tests include adhesive failure(a) (at the material interface), cohesive failure (B) (within one material), and mixed failure (c) (a combination of both). Adhesive failures suggest weak bonding, cohesive indicate material weakness, and mixed reflect shared contributions.

Statistical Analysis
Data were presented as mean ± standard deviation (SD). A two-way ANOVA was applied to assess the effects of luting agent and root region on push-out bond strength, and Tukey's post hoc test was used for pairwise comparisons. Statistical significance was defined at $\alpha = 0.05$, consistent with prior studies on zirconia-based restorations (Saisho et al., 2023; Su et al., 2025).

RESULTS

Descriptive Statistics of Push-Out Bond Strength
The overall mean push-out bond strength of zirconia posts across all groups and regions was **16.81 ± 5.09 MPa**, with recorded values ranging from **8.33 to 25.00 MPa**. These findings indicate a moderate level of post retention, consistent with previous literature describing the inherently weaker adhesion of zirconia compared with glass fiber posts (Attia and Kern, 2011; Goracci and Ferrari, 2011). The observed variability reflects the influence of both the luting agent and the root canal region, confirming that these factors exert a decisive effect on bonding performance (Efe and Güçlü, 2021).

Table 1: Descriptive Statistics of Push-Out Bond Strength According to Root Region.

Root Region	N	Minimum	Maximum	Mean ± SD
Apical (A)	10	8.33	35.00	15.88 ± 6.11
Cervical (C)	10	7.50	33.33	19.97 ± 6.35
Middle (M)	10	7.50	29.17	15.86 ± 5.69

Influence of Root Region
When comparing the anatomical thirds of the root canal (Table 2), the cervical slices consistently exhibited higher bond strength (**19.97 ± 6.35 MPa**) than both middle (**15.86 ± 5.69 MPa**) and apical slices (**15.88 ± 6.11 MPa**).

- Statistical analysis revealed that **cervical vs apical** (mean difference = **4.154 MPa**, $p < 0.001$) and **cervical vs middle** (mean difference = **4.115 MPa**, $p < 0.001$) comparisons were highly significant.
- Conversely, no significant difference was detected between apical and middle thirds ($p = 0.956$).

These results support the notion that cervical dentin, with its larger tubule diameter, higher tubule density, and more favorable curing conditions, provides a superior substrate for bonding compared with deeper regions.

It is also noteworthy that although mean values varied among specimens, the range of bond strength measurements (7.50–35.00 MPa) indicates substantial heterogeneity, which might reflect variations in dentin substrate quality or microstructural differences among individual teeth. Such biological variability must be considered when extrapolating laboratory results to clinical situations.

Table 2: Pairwise Comparisons of Root Canal Regions for Push-Out Bond Strength (Zirconia Post)
Dependent Variable: Push-Out Bond Strength (MPa)

(I) Area	(J) Area	Mean Difference (I–J)	Std. Error	Sig. (p)	95% CI (Lower – Upper)
Apical (Q)	Cervical (C)	-4.154*	0.694	0.000	-5.525 – -2.784
	Middle (M)	-0.039	0.704	0.956	-1.431 – 1.352
Cervical (C)	Apical (Q)	4.154*	0.694	0.000	2.784 – 5.525
	Middle (M)	4.115*	0.701	0.000	2.730 – 5.500
Middle (M)	Apical (Q)	0.039	0.704	0.956	-1.352 – 1.431
	Cervical (C)	-4.115*	0.701	0.000	-5.500 – -2.730

* Significant at $p < 0.05$.

Influence of Luting Agent
The type of cement exerted a significant effect on retention (**Table 3**).

- **Bulk-fill resin composite (BF)** recorded the highest mean values, significantly outperforming both RMGIC and SARC. Pairwise comparisons demonstrated that:
  - BF was superior to RMGIC (mean difference = **1.667 MPa**, $p = 0.019$).
  - BF was markedly superior to SARC (mean difference = **6.332 MPa**, $p < 0.001$).
- RMGIC also performed significantly better than SARC (mean difference = **4.665 MPa**, $p < 0.001$).

Thus, resin-based systems demonstrated a clear advantage over ionomer- and self-adhesive–based systems in terms of establishing durable bonds with zirconia.

Table 3: Pairwise Comparisons of Luting Agents for Push-Out Bond Strength Dependent Variable: Push-Out Bond Strength (MPa).

(I) Luting Agent	(J) Luting Agent	Mean Difference (I–J)	Std. Error	Sig. (p)	95% CI (Lower – Upper)
Bulk-fill resin (BF)	RMGIC	1.667*	0.704	0.019	0.276 – 3.058
	SARC	6.332*	0.697	0.000	4.955 – 7.709
RMGIC	BF	-1.667*	0.704	0.019	-3.058 – -0.276
	SARC	4.665*	0.698	0.000	3.286 – 6.044
SARC	BF	-6.332*	0.697	0.000	-7.709 – -4.955
	RMGIC	-4.665*	0.698	0.000	-6.044 – -3.286

* Significant at $p < 0.05$

Comparison of Post Types

Although zirconia posts demonstrated slightly lower push-out bond strength compared with glass fiber posts (mean difference = **–0.984 MPa**), this difference was not statistically significant (**p = 0.087**, Table 4). This finding suggests that zirconia posts, despite their less reactive surface, can achieve comparable retention to glass fiber posts when bonded with appropriate resin cements.

Table 4: Pairwise Comparison of Posts for Push-Out Bond Strength Dependent Variable: Push-Out Bond Strength (MPa).

Comparison	Mean Difference (I–J)	Std. Error	Sig. (p)	95% CI (Lower – Upper)
Zirconia vs GFP	-0.984	0.572	0.087	-2.113 – 0.145

Combined Effect of Root Region and Luting Agent

The interaction between luting agent and root region (**Table 4**) revealed distinct trends.

- The **highest bond strength** was obtained with **bulk-fill resin in the cervical third (27.667 ± 1.197 MPa)**.
- The **lowest bond strength** was recorded with **self-adhesive resin in the apical third (12.664 ± 1.197 MPa)**.
  Across all root levels, BF consistently outperformed both RMGIC and SARC. The cervical third consistently provided the most favorable bonding environment, while the apical region presented the greatest challenge to adhesive performance.

Failure Mode Analysis

Microscopic evaluation of debonded specimens (**Table 4**) revealed distinct failure patterns depending on the luting agent.

- **Bulk-fill resin (BF):** Predominantly cohesive failures (**67%**), indicating strong adhesion at the post–dentin interface and highlighting the inherent strength of the resin matrix.
- **RMGIC:** A more balanced distribution of failure types (adhesive = **27%**, cohesive = **40%**, mixed = **33%**), reflecting intermediate bonding performance.
- **Self-adhesive resin (SARC):** Predominantly adhesive failures (**50%**), consistent with the weaker interaction of SARC with both dentin and zirconia.
  These distributions substantiate the quantitative findings, underscoring the superior adhesive reliability of bulk-fill resin composites.

Table 5: Pairwise Comparisons of Root Region and Luting Agent on Push-Out Bond Strength. Dependent Variable: Push-Out Bond Strength (MPa)

Root Region	Luting Agent	Mean ± SD (MPa)	95% CI (Lower – Upper)
Apical	BF	13.835 ± 1.197	11.471 – 16.199
	RMGIC	14.100 ± 1.197	11.736 – 16.464
	SARC	12.664 ± 1.197	10.300 – 15.028
Cervical	BF	27.667 ± 1.197	24.303 – 29.031
	RMGIC	23.916 ± 1.197	21.552 – 26.280
	SARC	20.242 ± 1.197	17.878 – 22.606
Middle	BF	20.783 ± 1.197	18.419 – 23.147
	RMGIC	20.835 ± 1.261	18.471 – 23.199
	SARC	16.146 ± 1.338	13.504 – 18.788
Lowest subgroup	SARC–Apical	12.664 ± 1.197	10.300 – 15.028
Highest subgroup	BF–Cervical	27.667 ± 1.197	24.303 – 29.031

Key Numerical Highlights for Emphasis

- Overall mean push-out bond strength: **16.81 ± 5.09 MPa**.
- Cervical third significantly stronger (≈ **20 MPa**) vs apical/middle (≈ **15–16 MPa**).
- BF consistently strongest: cervical (**27.667 MPa**) > middle (**20.783 MPa**) > apical (**13.835 MPa**).
- SARC consistently weakest: cervical (**20.242 MPa**) > middle (**16.146 MPa**) > apical (**12.664 MPa**).
- Predominant failure with BF: **67% cohesive** vs SARC: **50% adhesive**.

Table 6: Mode of Failure Distribution in Zirconia Posts.

Luting Agent	Adhesive Failure (%)	Cohesive Failure (%)	Mixed Failure (%)
Bulk-fill resin (BF)	17%	67%	17%
RMGIC	27%	40%	33%
Self-adhesive resin (SARC)	50%	17%	33%

DISCUSSION

This study evaluated the push-out bond strength of zirconia posts cemented with three types of luting agents—bulk-fill resin composite (BF), resin-modified glass ionomer cement (RMGIC), and self-adhesive resin cement (SARC)—in the cervical, middle, and apical thirds of root canal dentin. The results showed that BF consistently produced the highest bond strength, followed by RMGIC, while SARC demonstrated the weakest performance. In addition, significantly greater bond strength was observed in the cervical third compared with the middle and apical regions, highlighting the impact of anatomical location on adhesive behavior.

Influence of Luting Agent

The superiority of bulk-fill resin composites over RMGIC and SARC may be attributed to their enhanced polymerization kinetics, greater depth of cure, and reduced polymerization shrinkage stress (Al-Aali et al., 2022). These properties allow bulk-fill systems to achieve more intimate adaptation to the radicular dentin walls and more effective micromechanical interlocking with surface irregularities. By contrast, the lower performance of RMGIC is explained by its reliance on ionic interaction with dentin and its susceptibility to hydrolytic degradation, which collectively compromise long-term stability in the moist intraradicular environment (Efe and Güçlü, 2021).

SARC demonstrated the weakest bond strength, consistent with earlier reports that self-adhesive systems are unable to achieve the same quality of interaction with zirconia or radicular dentin as multi-step resin systems (Attia and Kern, 2011). Their simplified chemistry, characterized by the use of acidic monomers without prior surface conditioning, results in limited infiltration and weaker adhesion. The predominance of adhesive failure modes (50%) in SARC specimens further corroborates this limitation, underscoring the inadequacy of this category for zirconia post cementation.

Influence of Root Region

The anatomical distribution of bond strength confirmed the hypothesis that cervical dentin provides a more favorable bonding substrate. Higher values in this region can be explained by the increased density and diameter of dentinal tubules, which facilitate deeper penetration of adhesive resins and allow for more effective micromechanical retention (Goracci and Ferrari, 2011). Additionally, the cervical third allows easier placement and manipulation of cement, and, in the case of resin-based systems, improved light transmission enhances polymerization efficiency. In contrast, the middle and apical thirds present challenges related to reduced tubule density, restricted access for cement delivery, and limited curing light penetration, leading to weaker bonding performance (Rigos et al., 2023).

Surface Properties of Zirconia

The inherently inert, polycrystalline nature of zirconia limits chemical interaction with conventional silane coupling agents, which explains why bond strengths in this study remained moderate compared with glass fiber posts (Attia and Kern, 2011; Kern, 2015). Although the difference between zirconia and glass fiber posts was not statistically significant ($p = 0.087$), the slightly lower mean values highlight the clinical necessity of optimizing adhesive strategies when using zirconia. Recent evidence suggests that functional monomers such as 10-MDP and surface conditioning techniques such as airborne particle abrasion and silica coating substantially improve adhesion (Li et al., 2024). These methods were not applied in the present study but represent promising directions for future investigations aiming to enhance the performance of zirconia post restorations.

Several clinical studies have reported early debonding of zirconia posts within two years of service, particularly when simplified cements such as SARC are used (Satpathy et al., 2024; John, 2025). This underscores the need for adjunctive surface treatments, such as airborne particle abrasion combined with 10-MDP primers, which have demonstrated superior chemical bonding and improved clinical survival rates. Consequently, the present results should be interpreted within the broader context of adhesive dentistry, where the integration of chemical primers and micromechanical conditioning remains the most promising pathway for enhancing zirconia bonding.

Clinical Implications

From a clinical perspective, the results suggest that bulk-fill resin composites should be prioritized for zirconia post cementation, particularly in the cervical region where the adhesive interface is most favorable. RMGIC, while providing acceptable retention, may be less reliable in the long term due to hydrolytic degradation, and SARC should be avoided given its consistently weak performance and high incidence of adhesive failures. These findings carry significant implications for the selection of luting agents in restorative dentistry, especially in cases requiring durable retention and esthetic stability in the anterior region.

Limitations

Several limitations must be acknowledged. First, the in vitro design does not fully replicate intraoral conditions, where thermal fluctuations, mechanical loading, and enzymatic activity contribute to degradation of the adhesive interface (Ehlers et al., 2020; Beketova et al., 2023). The absence of thermocycling and mechanical fatigue testing restricts extrapolation of results to long-term clinical scenarios. Second, only a single brand of zirconia posts and cements was investigated, limiting generalizability. Finally, the sample size (n = 10 per group), though comparable to similar studies, was relatively small and may not capture the full variability of clinical outcomes.

Additionally, the study did not incorporate thermomechanical fatigue, cyclic loading, or artificial aging protocols, which are known to accelerate degradation of the adhesive interface. Future research should therefore combine laboratory testing with simulated intraoral conditions and randomized clinical trials, in order to validate the long-term clinical applicability of bulk-fill resin composites and other emerging luting agents for zirconia post cementation.

CONCLUSION

This study demonstrated that both the luting agent and root canal region significantly affect zirconia post retention. Bulk-fill resin composites showed the highest bond strength, particularly in the cervical third, while RMGIC provided intermediate results and self-adhesive resin cements exhibited the weakest performance with predominantly adhesive failures. Clinically, bulk-fill resins appear to be the most reliable choice for zirconia post cementation, whereas self-adhesive systems should be avoided due to inferior bonding.

Future investigations should prioritize combining innovative resin formulations with advanced zirconia surface conditioning protocols to maximize bond durability. Moreover, long-term randomized controlled clinical trials are warranted to determine whether the superior in vitro performance of bulk-fill resin composites translates into sustainable outcomes under functional intraoral conditions.

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