A COMPARATIVE EVALUATION OF DIFFERENT FERRULE DESIGNS ON THE FRACTURE RESISTANCE OF RESTORATIONS OVER POST AND CORE TREATED PREMOLARS WITH PRE-FABRICATED FIBER POST: AN IN-VITRO STUDY

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ABSTRACT

Background: The ferrule effect reinforces endodontically treated teeth restored with post-and-core systems, yet evidence on how ferrule wall height and location affect fracture resistance remains limited. This study evaluated the influence of different ferrule designs on fracture resistance and failure patterns of post- and core-treated mandibular premolars restored with prefabricated fiber posts.

Materials and Methods: Forty-two extracted mandibular premolars were endodontically treated and randomly divided into three groups (n=14): Group A, 2 mm circumferential ferrule (control); Group B, 2 mm buccal/1 mm lingual ferrule; Group C, 1 mm buccal/2 mm lingual ferrule. All specimens received fiber posts, composite cores, and zirconia crowns, followed by thermocycling. Fracture resistance was measured using a Universal Testing Machine; failure modes were assessed visually, by stereomicroscopy, and by SEM. Data were analyzed using one-way ANOVA with post hoc Tukey's test ($p < 0.05$).

Results: Mean fracture resistance was highest in Group B (49.03 ± 22.90 N), followed by Group C (42.43 ± 21.11 N) and Group A (40.08 ± 11.32 N), with significant differences among all groups ($p < 0.05$–0.001). Failure mode analysis showed significant differences in fractures below the bone level and vertical root fractures across groups ($p < 0.05$).

Conclusion: Ferrule configuration significantly affects fracture resistance of post- and core-treated premolars. A buccally dominant ferrule design (2 mm buccal, 1 mm lingual) provided greater fracture resistance than the conventional circumferential and lingually dominant configurations, suggesting a biomechanical advantage relevant to restorative decision-making in teeth with asymmetric coronal structure loss.

Keywords: Ferrule effect; Fracture resistance; Fiber post; Post and core; Endodontically treated teeth; Zirconia crown

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INTRODUCTION

The structural integrity and functional performance of a natural tooth are primarily determined by its two principal components, enamel and dentin. Enamel, the highly mineralized and extremely hard outer layer, functions as the primary barrier against mechanical forces and chemical insults. [1] Dentin, located beneath the enamel, is comparatively less mineralized but exhibits greater elasticity and resilience, serving to support the enamel and absorb

functional stresses. Non-vital teeth exhibit distinct physical and mechanical properties compared to vital teeth. [2] The fracture resistance of pulpless teeth is influenced by multiple factors, including the extent of structural loss, the presence and configuration of a ferrule, the tooth's position within the dental arches, the type of post-and-core system employed, the restorative material's ability to compensate for lost tooth substance, and the use of resin cement. [3] Both tissues undergo structural and mechanical alterations following root canal therapy (RCT). Although enamel is not directly subjected to chemical treatment during RCT, long-term changes occur indirectly due to dehydration, loss of supporting dentin, and alterations in stress distribution. [4]

Numerous authors, have emphasized the clinical importance of preserving the maximum possible amount of sound dentin during the restoration of endodontically treated teeth (ETT). These teeth are predisposed to crown fractures owing to extensive coronal structure loss, dehydration, and changes in the bio-mechanical behavior of pulpless teeth. Consequently, full coronal coverage restorations are indicated to counteract occlusal loading forces. When more than half of the coronal structure is lost, post-and-core systems with full coverage crowns are generally required. Posts serve to provide retention and resistance for the core material, while the core stabilizes the corono-radicular complex. [5-7]

Endodontic posts may be prefabricated or custom-made, and classified as metallic or non-metallic. Conventional custom-cast metal posts, though widely used historically, are time- intensive, unaesthetic, and mechanically incompatible with dentin. [8] Advances in restorative dentistry and increased esthetic demands have led to the development of prefabricated, tooth-colored posts with improved physical properties, including carbon fiber, glass fiber-reinforced composite, quartz, ceramic post, and zirconia posts. The adhesive bonding potential of fiber-reinforced posts enhances retention, optimizes stress distribution, and reinforces residual tooth structure, advantages not achievable with cast metal posts. [9] Cast posts are prone to corrosion and exhibit a modulus of elasticity markedly different from dentin, predisposing the tooth to root fracture.

Comparative studies further highlight material-specific advantages. Raju et al. reported that quartz fiber posts demonstrate superior flexural strength compared to glass and composite-reinforced fiber posts, attributing their favorable performance to enhanced resistance against root fractures. [5] Tortopidis et al. documented highly esthetic outcomes when using fiber-reinforced composite posts with all-ceramic crowns. Abduljawad et al. observed increased fracture resistance with glass fiber posts in ETT. The modulus of elasticity of metallic posts (≈220,000 MPa) is approximately twenty times greater than that of dentin (≈20,000 MPa), whereas glass fiber posts (≈54,000 MPa) exhibit values closer to dentin, thereby reducing stress concentration and minimizing the risk of root fracture. [6]

The ferrule effect, a 360° collar of residual coronal dentin incorporated into the crown preparation, plays a crucial role in reinforcing endodontically restored teeth. Depending on the location and configuration of surviving tooth walls, extensive coronal damage may result in a partial ferrule with varied patterns. Clinical evidence suggests that partial ferrules are biomechanically superior to the absence of a ferrule, and certain partial ferrule designs may perform comparably to complete ferrules. [10-11]

Given this context, understanding the bio-mechanical implications of different ferrule designs is critical. Optimizing fracture resistance depends not only on the height, location, and number of remaining coronal walls, but also on factors such as post material, post design, post length, cementation protocol, and crown material composition. However, the limited number of studies evaluating the clinical utility of varying ferrule configurations has contributed to ongoing controversy. [12]

To address this gap, the present study investigates the effect of partial ferrule designs, specifically partial lingual and partial buccal wall configurations with variable wall heights, on the fracture resistance and failure modes of mandibular premolars restored with prefabricated fiber posts. This approach reflects the common clinical challenge of achieving optimal ferrule dimensions in post-and-core treated teeth. By assessing how variations in ferrule height and wall distribution influence mechanical performance, the study seeks to determine the minimal structural requirements for an effective ferrule. Accordingly, the objective is to evaluate the influence of different ferrule heights on remaining coronal walls and their subsequent impact on fracture resistance and failure patterns in endodontically treated premolars restored with prefabricated fiber posts, composite cores, and all-ceramic crowns. The results are expected to inform evidence-based clinical guidelines for ferrule design in restorative dentistry.

METHODOLOGY:

The current analysis was designed as an in-vitro analysis on 42 samples. The study samples were included on the basis of inclusion and exclusion criteria.

Selection of patient

Forty-two freshly extracted, with intact human mandibular premolars and a single canal and fully developed apices were selected. Teeth exhibiting internal resorption, root cracks, gross caries,

calcified canals, previous endodontic treatment, or open apices were excluded.

Specimen Preparation

Following ultrasonic debridement, teeth were stored in artificial saliva until use. Pre-operative radiographs were obtained to confirm the absence of fractures, resorptive defects, canal calcification, and endodontic filling materials. Standardized endodontic treatment was performed using rotary instrumentation, followed by obturation with gutta-percha and sealer. Each specimen was embedded vertically in auto-polymerizing acrylic resin within cylindrical molds, with the resin margin positioned 2 mm apical to the cementoenamel junction (CEJ) to simulate alveolar bone support, ensuring standardization using a dental surveyor.

Materials and Equipment

Artificial saliva (Modified Fusayama), autopolymerizing acrylic resin (DPI-RR Cold Cure), zirconia blocks (Jyodent, A1 shade), gutta-percha points (DiaDent), MANI K-files, 0.9% saline (Ultra-care), flowable composite (DMG Constic), hydrofluoric acid (UltraDent Porcelain Etch), 37% phosphoric acid (3M ESPE Scotchbond), bonding agent (3M ESPE Single Bond Universal), silane coupling agent (Prevest DenPro), dual-cure resin cement (3M ESPE RelyX U200), Kerr Sealapex sealer, fiber post (Medicept Selfpost), dual-cure core build-up material (DMG LuxaCore Dual).

Armamentarium

Hand gloves, mouth mask, porcelain jar, wax instruments, 24×25 mm acrylic cylinders, high-speed turbine (Allure Prime), laboratory micromotor (Marathon-4), contra-angle handpiece (Being Foshan), rotary endomotor (Dentsply X-Smart), universal rotary files (Dentsply Maillefer), Peeso reamers, Gates-Glidden drills (Mani Inc.), diamond burs (MANI), ultrasonic scaler (Unicorn P6), laboratory scanner (Medit T500), CAD/CAM software (EXOCAD Matera v2.3), dental surveyor (Saeyang), light-curing unit (Unicorn UE), thermocycling machine (RK-STD-28/48), dry milling machine (Roland DWX-52D), Universal Testing Machine (TUF-C-600, Servo), stereomicroscope (Micron Optik INV-3i), and SEM (TESCAN MIRA3 LMH).

Ferrule Preparation

Coronal reduction was performed to maintain 2 mm of tooth structure coronal to the CEJ. A uniform heavy chamfer finish line (1 mm width) was prepared under water-cooled high-speed rotary instrumentation. Ferrule heights were standardized using calipers and a periodontal probe, and specimens were randomly allocated (n=14 per group) into:

- **Group A (Control):** 2 mm circumferential ferrule
- **Group B:** 2 mm facial ferrule and 1 mm lingual ferrule
- **Group C:** 1 mm facial ferrule and 2 mm lingual ferrule

Post Space Preparation and Core Build-Up

Post space was prepared using Peeso reamers (#4) and Gates-Glidden drills (#5), maintaining a 4–5 mm apical seal verified radiographically. A 1.3 mm diameter fiber-reinforced composite post (size #3) was trial-fitted. Post spaces were irrigated with 0.9% normal saline, dried, etched for 15 s, rinsed, and conditioned with universal adhesive. Posts were luted with dual-cure resin cement, and composite resin core build-up was performed to extend 5 mm above the ferrule.

Crown Preparation and Fabrication

Standardized tooth preparation for monolithic zirconia crowns was executed with a 1 mm heavy chamfer finish line, rounded internal line angles, and smoothed surfaces using fine-grit diamond burs. Each specimen was digitally scanned (laboratory-grade scanner), and 42 STL files were generated. Crown designs were completed in EXOCAD software and milled from A1-shade zirconia blocks using a 5-axis dry milling machine.

Cementation Protocol

The intaglio surfaces of zirconia crowns were air-abraded with 110 µm alumina, cleaned with alcohol, and air-dried. Dual-cure resin cement was applied, crowns were seated with finger pressure, tack-cured for 2 s, excess cement was removed, and final polymerization was achieved with 20 s light curing on each surface.

Thermomechanical Aging

Following cementation, specimens were stored for 24 h at room temperature before aging. Thermocycling (5,000 cycles, 5 °C–55 °C, 30 s dwell) was performed to simulate oral thermal stress. Specimens were then stored in distilled water at 37 °C for 24 h at 100% humidity.

Fracture Resistance Testing

Specimens were mounted in a Universal Testing Machine with a 4 mm piston tip aligned along the long axis. Vertical static loading was applied at the central fossa at 1 mm/min until crack initiation. The load at fracture initiation was recorded in kilonewtons (kN).

Fractographic Analysis

Fractured specimens were examined in three sequential stages:

1. **Visual inspection** for macrofractures and crack lines.
2. **Stereomicroscopy** (40× magnification) to locate fracture origin.



Fig. Stereo-microscopic Examination of Group A



Fig. Stereo-microscopic Examination of Group B

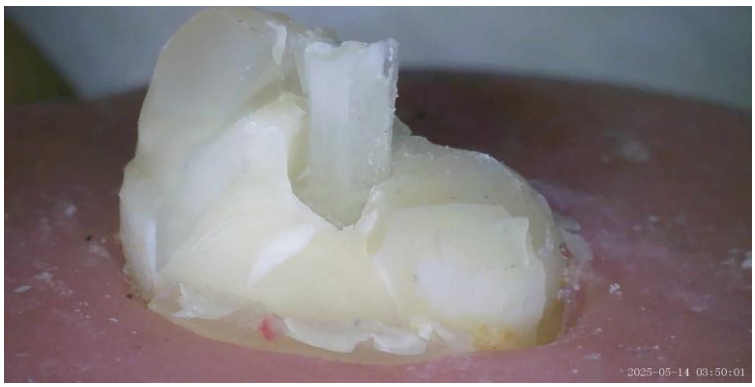


Fig . Stereo-microscopic Examination of Group C

3. **Scanning Electron Microscopy (SEM)** (130–200×) for detailed assessment of crack origin, propagation, micro-cracks, arrest lines, hackles, compression curls, and wake hackles.

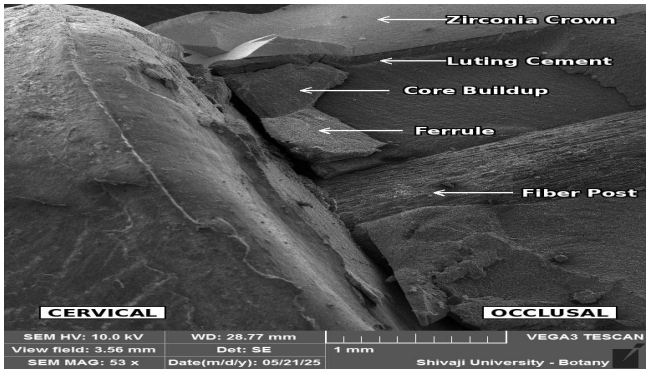


Fig . Cross Section of Fractured Segment

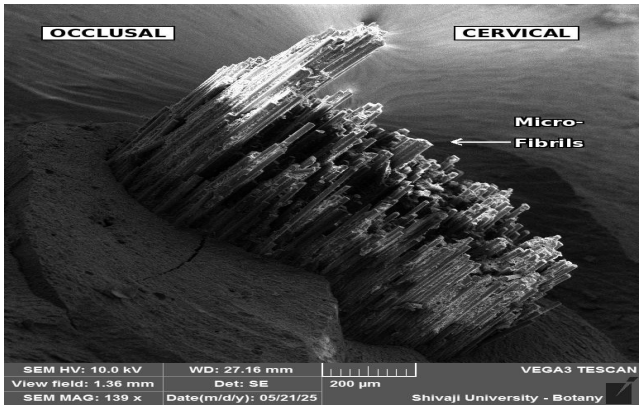


Fig . Cross Section of Fractured Fiber Post showing Micro-Fibrils

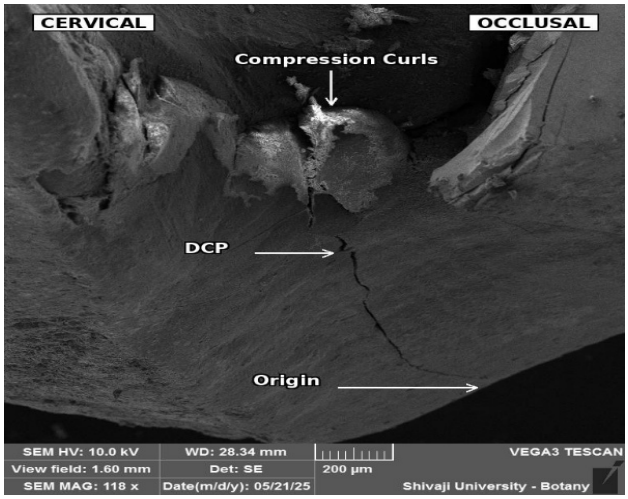


Fig. Direction of failure mode (DCP) and compression curls

Statistical Analysis

Data were entered into Microsoft Excel (2009) and analyzed using SPSS v25.0. Normality was verified using Kolmogorov–Smirnov and Shapiro–Wilk tests ($p > 0.05$). Descriptive statistics were expressed as mean ± standard deviation. Intragroup comparisons were performed using paired t-tests, and intergroup differences were assessed via one-way ANOVA with post hoc Tukey's test. Statistical significance was set at $p < 0.05$, with thresholds: $p < 0.05$ (significant), $p < 0.01$ (highly significant), $p < 0.001$ (very highly significant).

Observations and result:-

TABLE 1 : Comparison for fracture resistance between (Group A) and (Group B)

Fracture resistance	2mm Circumferential Ferrule (Control group) (Group A)	2mm buccal half ferrule and 1 mm lingual half ferrule (Group B)
Mean change	40.08	49.03
Standard deviation (SD)	11.32	22.90
Mean difference	-8.95	
P-value	**<0.001****	

The study compared the fracture resistance between Group A (2 mm circumferential ferrule – control group) and Group B (2 mm buccal half ferrule and 1 mm lingual half ferrule). The mean fracture resistance in Group A was 40.08 with a standard deviation of 11.32, whereas Group B showed a higher mean value of 49.03 with a standard deviation of 22.90. The mean difference between the groups was -8.95. The comparison revealed a statistically significant difference with a p-value of <0.001, indicating that the modified ferrule design in Group B significantly improved fracture resistance compared to the control.

Table 2: Comparison for fracture resistance between (Group A) and (Group C)

Fracture resistance	2mm Circumferential Ferrule (Control group) (Group A)	1mm buccal half ferrule and 2mm lingual half ferrule (Group C)
Mean change	40.08	42.43
Standard deviation (SD)	11.32	21.11
Mean difference	2.35	
P value	**<0.05***	

The study compared the fracture resistance between Group A (2 mm circumferential ferrule – control group) and Group C (1 mm buccal half ferrule and 2 mm lingual half ferrule). The mean fracture resistance in Group A was 40.08 with a standard deviation of 11.32, while Group C had a slightly higher mean of 42.43 and a standard deviation of 21.11. The mean difference between the groups was 2.35. The difference was found to be statistically significant with a p-value of <0.05, suggesting that the ferrule design in Group C offered a modest but significant improvement in fracture resistance compared to the control.

TABLE 3 : Comparison for fracture resistance between (Group B) and (Group C)

Fracture resistance	**2mm buccal half ferrule and 1 mm lingual half ferrule (Group B)**	**1mm buccal half ferrule and 2mm lingual half ferrule (Group C)**
Mean	49.03	42.43
Standard deviation (SD)	22.90	21.11
Mean difference	6.60	
P value	**<0.05***	

The study compared the fracture resistance between Group B (2 mm buccal half ferrule and 1 mm lingual half ferrule) and Group C (1 mm buccal half ferrule and 2 mm lingual half ferrule). Group B demonstrated a higher mean fracture resistance of 49.03 with a standard deviation of 22.90, while Group C showed a mean of 42.43 with a standard deviation of 21.11. The mean difference between the two groups was 6.60. This difference was statistically significant, with a p-value of <0.05, indicating that the ferrule configuration in Group B provided superior fracture resistance compared to Group C.

Table 4: Comparison of Post and Core Failure Parameters Among Three Groups

Parameters evaluated	**complete debonding of post and core (and crown)**	**partial debonding of core/crown**	**fracture of post-core-tooth complex above bone level**	**fracture of post-core-tooth complex below bone level**	**(vertical) root fracture**	**cracks below bone level**
Group A						
Total sample (n=14)	1	3	3	5	2	0
% involvement	7%	21%	21%	35%	14%	0%
Group B						

Total sample (n=14)	2	3	3	5	1	0
% involvement	14%	21%	21%	35%	7%	0%
Group C						
Total sample (n=14)	2	2	3	4	3	0
% involvement	14%	14%	21%	28%	21%	0%
P value	>0.05	>0.05	0.05	<0.05*	<0.05*	>0.05

The study compared post and core failure parameters among three groups with different ferrule designs. In Group A, complete debonding of the post and core (including crown) was observed in 1 case (7%), partial debonding in 3 cases (21%), fractures above the bone level in 3 cases (21%), and fractures below the bone level in 5 cases (35%). Vertical root fractures occurred in 2 cases (14%), while no cracks below the bone level were reported. Group B showed complete debonding in 2 cases (14%), partial debonding in 3 cases (21%), and fractures above and below the bone level in 3 (21%) and 5 (35%) cases respectively. One case (7%) exhibited a vertical root fracture, and no cracks below bone level were noted. In Group C, complete and partial debonding occurred in 2 cases each (14% and 14%, respectively), fractures above the bone level were seen in 3 cases (21%), and below bone level in 4 cases (28%). Vertical root fractures were noted in 3 cases (21%), with no cases of cracks below bone level. Statistical analysis revealed significant differences among the groups for fractures below the bone level and vertical root fractures ($p < 0.05$), while other parameters showed no statistically significant differences ($p > 0.05$).

Discussion:

The ferrule is believed to enhance the longevity of restored teeth by reinforcing the tooth, prosthesis complex and increasing fracture resistance through improved stress distribution. [13-14] Evidence suggests that maintaining approximately 2 mm of coronal tooth structure above the finish line optimizes this effect, although some studies report no additional benefit. [15-16] While limited research has explored the influence of varying ferrule designs on fracture resistance, endodontic literature consistently supports that, whether complete or partial, the presence of a ferrule improves resistance to functional, wedging, and lateral forces. [17-18]

The present in-vitro study evaluated the influence of different ferrule designs on the fracture resistance and failure patterns of post- and core-treated premolars restored with prefabricated fiber posts.

When comparing the control group (Group A: 2 mm circumferential ferrule) with Group B (2 mm buccal half ferrule and 1 mm lingual half ferrule), the mean fracture resistance increased from 40.08 ± 11.32 N in Group A to 49.03 ± 22.90 N in Group B. The mean difference of -8.95 N was statistically significant ($p < 0.001$), indicating that the modified non-uniform

ferrule design in Group B provided superior fracture resistance compared to the conventional circumferential ferrule.

In contrast, Group C (1 mm buccal half ferrule and 2 mm lingual half ferrule) demonstrated only a marginal improvement in fracture resistance (42.43 ± 21.11 N) compared to the control (40.08 ± 11.32 N). The mean difference of 2.35 N was statistically significant ($p < 0.05$), suggesting that although the altered ferrule configuration in Group C resulted in a modest gain in fracture resistance, the effect size was notably smaller than that observed in Group B.

Direct comparison between the two non-uniform ferrule groups revealed a higher mean fracture resistance in Group B (49.03 ± 22.90 N) compared to Group C (42.43 ± 21.11 N), with a mean difference of 6.60 N ($p < 0.05$). This confirms that the buccally dominant ferrule height (2 mm buccal, 1 mm lingual) in Group B was biomechanically more favorable than the lingually dominant ferrule height (1 mm buccal, 2 mm lingual) in Group C.

Evaluation of post and core failure parameters across the three groups revealed that complete debonding of the post–core–crown complex occurred in 7%, 14%, and 14% of samples in Groups A, B, and C, respectively ($p > 0.05$). Partial debonding was noted in 21% of specimens in both Groups A and B, and 14% in Group C ($p > 0.05$). Fractures of the post–core–tooth complex above the bone level occurred in 21% of samples across all groups ($p = 0.05$).

Fractures below the bone level were observed in 35% of samples in Groups A and B, and 28% in Group C, with the difference being statistically significant ($p < 0.05$). Vertical root fractures were recorded in 14%, 7%, and 21% of samples in Groups A, B, and C, respectively, also showing statistical significance ($p < 0.05$). No cracks below the bone level were detected in any group.

Overall, the findings indicate that non-uniform ferrule designs can influence the fracture resistance of restored premolars, with a buccally dominant ferrule height (Group B) demonstrating the greatest improvement. While Group C also showed a statistically significant increase compared to the control, the effect was comparatively limited. The pattern of failures suggests that although ferrule configuration affects fracture resistance, catastrophic failures such as vertical root fractures and fractures below the bone level remain a clinical concern.

However, Juloski et al., emphasized that the optimal ferrule effect requires a height of 1–2 mm, parallel dentinal walls, complete circumferential coverage, termination on sound tooth structure, and preservation of the periodontal attachment apparatus. In alignment with recommendations by Samaran et al., Qualtrough AJ et al., and Stankiewicz N et al., a 2 mm height and width ferrule was selected to maximize functional benefit. Abdulrazzak SS et al. further demonstrated that a 4 mm ferrule height achieved the highest mean failure load (536.7 N), significantly outperforming the 2 mm (414.6 N) and 0 mm (319.8 N) groups, irrespective of post length. [19-23]

"Previous literature has suggested that variations in dentin composition may influence dentin resilience and alter fracture patterns; however, limited evidence exists comparing how different ferrule designs can potentially mitigate these effects, as demonstrated by the significant differences in fracture resistance observed in the present study." [24-25] Thus, to sheds light on this limitations our current study provides clinically relevant evidence that strategic modification of ferrule design can enhance structural performance, thereby informing restorative decision-making and potentially improving long-term treatment outcomes."

Conclusion:

Within the limitations of this in-vitro study, ferrule configuration was found to significantly influence the fracture resistance of post- and core-treated premolars restored with prefabricated fiber posts. A buccally dominant ferrule height (2 mm buccal, 1 mm lingual) provided the highest fracture resistance, outperforming both the conventional circumferential ferrule and the lingually dominant ferrule configuration. Although all ferrule designs exhibited some degree of catastrophic failures, the buccally dominant design demonstrated a bio-mechanical advantage that may be clinically beneficial in cases with asymmetric coronal tooth structure loss. These findings highlight the importance of strategic ferrule design selection in optimizing restoration longevity, particularly in structurally compromised premolars.

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