Comparative Evaluation of Ferrule Design and Periodontal Support on the Longevity of Endodontically Treated Teeth

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Abstract

Background: Ferrule design and periodontal support are key factors in how long endodontically treated teeth last. This study looked at how both factors together affect the fracture resistance of teeth restored with glass fibre posts and zirconia crowns.

Materials and Methods: Sixty extracted human mandibular premolars were randomly divided into four groups (n = 15) based on ferrule design (2-mm ferrule or no ferrule) and periodontal support (normal or reduced). After standard endodontic treatment and restoration, all samples went through thermocycling, cyclic loading, and fracture resistance testing with a universal testing machine. Data were analyzed with one-way ANOVA and Tukey's post hoc test.

Results: Teeth restored with a 2-mmResults: Teeth with a 2-mm ferrule and normal periodontal support had the highest fracture resistance. Those without a ferrule and with reduced periodontal support had the lowest. The differences between groups were statistically significant ($p < 0.05$).equate 2-mm ferrule and favourable periodontal support significantly enhances the fracture resistance and anticipated longevity of endodontically treated teeth. Preservation of coronal tooth structure should be regarded as an essential aspect of restorative treatment planning.

Keywords: Ferrule effect; Periodontal support; Endodontically treated teeth; Fracture resistance; Glass fibre post; Zirconia crown; Crown-to-root ratio; Restoration longevity.

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INTRODUCTION

Endodontically treated teeth need careful restoration to last over time. Even with better materials and adhesives, their longevity still depends on biomechanical and biological factors. Ferrule design and periodontal support are especially important for restoration survival and fracture resistance **[1]**.

The ferrule effect has been widely studied for its role in improving the strength of endodontically treated teeth. Hajeer et al. found that the right ferrule size leads to better outcomes and higher fracture resistance, highlighting the need to keep healthy coronal tooth structure during restoration **[1]**.

In addition to ferrule design, periodontal support is important for the long-term success of restored teeth. Alveolar bone support and crown-to-root ratio affect how forces are distributed and how stable the restoration is. Sisodia et al. stressed that a good crown-to-root ratio is key for successful treatment of endodontically and periodontally treated teeth with crowns **[2]**.

New adhesive restorative techniques also aim to preserve as much tooth structure as possible. Bonchev reported good results using postless fibre-reinforced composite restorations with immediate dentin sealing and an internal adhesive ferrule. This suggests that conservative approaches can work well in some cases **[3]**.

Ferrule height directly affects fracture resistance. Rathaur et al. showed that higher ferrule height greatly improves the fracture resistance of teeth restored with glass fibre posts. Their results support keeping coronal dentin for better tooth strength **[4]**.

Recent reviews have also stressed the importance of ferrule shape. Dong et al. found that incomplete ferrule designs lower fracture resistance, so a full circumferential ferrule should be used whenever possible to help restorations last longer **[5]**.

Apart from ferrule height, the choice oBesides ferrule height, the type of restorative material also matters. Albashaireh and Sbeih found that both ferrule design and core material have a big impact on the fracture resistance of anterior teeth restored with ceramic crowns after aging **[6]**. Likewise, de Carvalho et al. showed that not having a ferrule lowers fatigue resistance and raises the risk of failure under repeated loading [7].n and periodontal support has attracted increasing attention in recent years. Meng et al. demonstrated that both ferrule height and crown-to-root ratio significantly affect the fracture resistance of endodontically treated premolars restored with either fibre posts or cast metal posts, indicating that restorative and periodontal factors should be evaluated together during treatment planning **[8]**. Supporting this evidence, Mosharaf et al. showed using finite element analysis that ferrule dimensions, crown-to-root ratio, and post length jointly influence stress and stress and strain distribution within endodontically treated teeth **[9]**.

New restorative biomaterials like polyetheretherketone (PEEK) posts have good biomechanical properties. However, Lima et al. found that even with better stress distribution from PEEK posts, keeping as much tooth structure as possible and using the right restorative design are still needed for good results **[10]**.

While recent studies have improved our understanding of ferrule design, materials, and periodontal support, there is little data on how these factors together affect the longevity of endodontically treated teeth. This study was done to evaluate how ferrule design and periodontal support together influence the endurance and strength of these teeth.

Methodology

This **in vitro comparative experimental study** was designed to evaluate the influence of ferrule design and periodontal support on the longevity of endodontically treated teeth. The research was conducted in the Department of Prosthodontics in collaboration with the Department of Conservative Dentistry and Endodontics, following approval from the Institutional Ethics Committee. Sixty **freshly extracted human mandibular premolars** with single roots and single canals were selected. Inclusion criteria comprised teeth with fully developed apices, similar root dimensions, and absence of caries, restorations, cracks, fractures, root resorption, or developmental anomalies. Exclusion criteria consisted of severe root curvature, previous endodontic treatment, extensive structural defects, or root fractures.

The selected teeth were cleaned using an ultrasonic scaler to remove soft tissue remnants and calculus and were stored in **0.1% thymol solution** until use. Standardized access cavity preparation was performed, followed by biomechanical preparation using ProTaper Gold rotary files up to size F3. The root canals were irrigated with **3% sodium hypochlorite** during instrumentation, followed by a final rinse with **17% EDTA** and normal saline. Obturation was completed using gutta-percha and AH Plus resin sealer by the lateral condensation technique. Post space preparation was carried out while maintaining **4 mm of apical gutta-percha**.The specimens were randomly allocated into four groups (n = 15 each) using a computer-generated randomization sequence.

Group I: Teeth restored with a **2-mm ferrule** and **normal periodontal support**.

Group II: Teeth restored with a **2-mm ferrule** and **reduced periodontal support**.

Group III: Teeth restored **without a ferrule** and **normal periodontal support**.

Group IV: Teeth restored **without a ferrule** and **reduced periodontal support**.

Ferrule preparation was standardized using a custom-made preparation guide. Normal periodontal support was simulated by embedding the roots in self-cure acrylic resin up to **2 mm apical to the cementoenamel junction (CEJ)**. Reduced periodontal support was simulated by embedding the roots **5 mm apical to the CEJ**, representing approximately 50% alveolar bone loss. A **0.25-mm layer of light-body addition silicone** was applied around the root surface before embedding to simulate the periodontal ligament.Prefabricated glass fibre posts (1.2 mm diameter) were cemented using dual-cure self-adhesive resin cement. Composite resin core build-ups were fabricated with a standardized core-forming matrix to ensure uniform dimensions. Tooth preparations were completed with a 1-mm chamfer finish line and a 6° total occlusal convergence. Full-coverage monolithic zirconia crowns of standardized dimensions were fabricated using CAD/CAM technology and were cemented with dual-cure resin cement according to the manufacturer's instructions. All specimens underwent **thermocycling for 5,000 cycles** between **5°C and 55°C**, with a dwell time of 30 seconds and a transfer time of 10 seconds. Subsequently, cyclic mechanical loading of **100,000 cycles at 100 N** was applied using a chewing simulator to replicate approximately six months of clinical function. Fracture resistance testing was carried out using a **Universal Testing Machine (Instron 3366, Instron Corp., Norwood, MA, USA)**. A compressive load was applied at an angle of **135° to the long axis of the tooth** with a stainless-steel loading tip at a crosshead speed of **1 mm/min** until catastrophic failure occurred. The maximum fracture load was recorded in **Newtons (N)**. Failure modes were evaluated under magnification and classified as **restorable** (fracture above the simulated bone level) or **non-restorable** (fracture extending below the simulated bone level). The primary outcome measure was fracture resistance, while secondary outcomes included mode of failure and the influence of ferrule design and periodontal support on restoration survival following fatigue loading. Data were entered into Microsoft Excel and analyzed using **IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA)**. Data distribution was assessed with the **Shapiro–Wilk test**. Descriptive statistics were reported as mean and standard deviation. Intergroup comparisons were performed using **one-way analysis of variance (ANOVA)** followed by **Tukey's post hoc test**. A **p-value less than 0.05** was considered statistically significant.

RESULTS

A total of **60 endodontically treated mandibular premolars** were included in the study and equally distributed into four groups (n = 15 each). Fracture resistance values were recorded in Newtons (N) after thermocycling and cyclic mechanical loading. Data were analyzed using one-way ANOVA followed by Tukey's post hoc test.

Table 1. Distribution of Specimens

Group	**Ferrule Design**	**Periodontal Support**	**n**
Group I	2-mm Ferrule	Normal	15
Group II	2-mm Ferrule	Reduced	15
Group III	No Ferrule	Normal	15
Group IV	No Ferrule	Reduced	15
Total			60

Table 2. Comparison of Mean Fracture Resistance

Group	**Mean ± SD (N)**
Group I	1128.6 ± 82.4
Group II	962.8 ± 75.1
Group III	875.3 ± 68.9
Group IV	702.5 ± 61.7

Interpretation:

The highest fracture resistance was observed in **Group I (2-mm ferrule with normal periodontal support)**, whereas **Group IV (no ferrule with reduced periodontal support)** demonstrated the lowest fracture resistance.

Table 3. One-Way ANOVA for Fracture Resistance

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Between Groups	1,492,840	3	497,613.3	56.84	<0.001*
Within Groups	490,150	56	8,752.7		
Total	1,982,990	59			

*Statistically significant (p < 0.05)

Interpretation:

There was a statistically significant difference in fracture resistance among the four groups (p < 0.001).

Table 4. Tukey's Post Hoc Comparison

Comparison	**Mean Difference (N)**	**p-value**
Group I vs Group II	165.8	<0.001*
Group I vs Group III	253.3	<0.001*
Group I vs Group IV	426.1	<0.001*
Group II vs Group III	87.5	0.021*
Group II vs Group IV	260.3	<0.001*
Group III vs Group IV	172.8	<0.001*

*Statistically significant

Table 5. Mode of Failure

Group	**Restorable n (%)**	**Non-restorable n (%)**
Group I	12 (80.0%)	3 (20.0%)
Group II	10 (66.7%)	5 (33.3%)
Group III	8 (53.3%)	7 (46.7%)

Group IV	5 (33.3%)	10 (66.7%)

DISCUSSION

This in vitro study assessed the combined influence of ferrule design and periodontal support on the fracture resistance and longevity of endodontically treated teeth restored with glass fibre posts and zirconia crowns. The results indicated that specimens restored with a 2-mm ferrule and normal periodontal support displayed superior fracture resistance compared to those restored without a ferrule or with reduced periodontal support. The favourable performance of teeth with an adequate ferrule corresponds to the findings of **Lima et al. [10]**, who reported that, although newer post materials such as polyetheretherketone (PEEK) improve stress distribution, preservation of the remaining coronal tooth structure remains the most critical determinant of biomechanical success. The present findings similarly suggest that ferrule design exerts a greater influence on fracture resistance than restorative material alone. The beneficial effect of ferrule preparation observed in this study is consistent with the recent meta-analysis by **J Prosthodontic Research [11]**, which concluded that even a partial ferrule significantly improves fracture resistance compared to teeth restored without a ferrule. The higher fracture resistance observed in the ferrule groups of this study supports this conclusion. The importance of ferrule preparation has also been emphasized in the literature review by **Assiri et al. [12]**, who stated that a continuous circumferential ferrule improves stress distribution, reduces the risk of vertical root fracture, and enhances restoration longevity. Similar biomechanical behaviour was observed in the current investigation, where specimens with an adequate ferrule displayed better resistance to fracture.

The influence of ferrule design on restorations fabricated with zirconia has also been reported by **Bamajboor and Dudley [13]**, who demonstrated that the presence of a ferrule significantly increased fracture resistance and improved marginal adaptation of zirconia endocrowns. Since zirconia crowns were also used in the present study, these observations support the improved mechanical performance obtained in specimens restored with a ferrule.Similarly, **Buyukerkmen et al. [14]** reported that increasing ferrule height significantly improves the retention and mechanical stability of monolithic zirconia restorations irrespective of the luting agent used. Their findings agree with the present results, where teeth restored with a 2-mm ferrule demonstrated significantly greater fracture resistance than those without ferrule preparation.

Finite element analysis by **Gatkal et al. [15]** demonstrated that increasing ferrule height reduces stress concentration within both the root and post system. The present study supports these outcomes, indicating that preservation of coronal dentin contributes to more favourable stress distribution during functional loading. Similarly, **Zahran et al. [16]** reported that both ferrule height and ferrule distribution significantly affect fracture resistance, with complete circumferential ferrules providing superior biomechanical performance. The higher fracture resistance observed in the ferrule groups of this investigation is consistent with these results. **Rocca et al. [17]** also demonstrated that the ferrule effect significantly improves marginal integrity and fracture load of CAD/CAM restorations in severely damaged premolars. Although the restorative protocol differed from the present study, both investigations underline the criticality of preserving coronal tooth structure for enhancing restoration longevity. Furthermore, **Xie et al. [18]** observed that increasing ferrule thickness considerably increased fracture resistance in endodontically treated incisors restored with fibre posts and metal crowns. The present findings similarly demonstrate that adequate ferrule preparation substantially contributes to the biomechanical stability of restored teeth. Overall, this study confirms that preservation of an adequate ferrule, together with favourable periodontal support, significantly improves fracture resistance and promotes more favourable biomechanical behaviour. These data are consistent with contemporary evidence from recent in vitro studies, systematic reviews, and finite element analyses **[10–18]**. However, as this investigation was conducted under laboratory conditions, further long-term clinical studies are necessary before these outcomes can be generalized to routine clinical practice.

Conclusion

Within the limitations of this in vitro study, both ferrule design and periodontal support were found to substantially affect the fracture resistance of endodontically treated teeth. Teeth restored with a 2-mm ferrule and normal periodontal support exhibited the highest fracture resistance, whereas the absence of a ferrule combined with reduced periodontal support resulted in the least favourable outcomes. Preservation of an adequate ferrule and healthy periodontal support should be given priority to enhance the endurance and clinical success of restorations in endodontically treated teeth.

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