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The Effect of Crown Ferrule Designs on Fracture Resistance of Endodontically Treated Teeth Restored with Fibre Posts, Composite Cores, And Crowns: An In-Vitro Study

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ABSTRACT

Objective: This study aimed to evaluate effect of crown ferrule designs on fracture-resistance of restored endodontically treated teeth with fiber posts, cores, and crowns.

Methods: Fifty six maxillary Central incisor were treated endodontically and divided into 4 groups with 14 teeth each; Group 1 with no ferrule (0FR); Group 2 with 2 mm circumferential ferrule (2FR); Group 3 with ferrule in labial, mesial and palatal side (2FR-LaMPa); Group 4 with ferrule in labial and palatal region(2FR-LaPA). All teeth were then restored with fiber-posts, composite cores and metal crowns. The samples were then subjected to load until failure occurred. Data were analyzed through one way analysis of variance and Tukey tests.

Results: Significant differences were found between each study group and the control group. The study found that specimens with tooth preparations containing axial walls had significant more fracture-resistance compared to those from the 0FR group. Additionally, teeth with complete ferrule showed inferior fracture-resistance, possibly due to a smaller adhesive area for core built-up compared to teeth with interrupted ferrule, having larger bonding surface areas. Conclusion: The fracture-resistance of restored endodontically treated teeth with incomplete crown ferrules may be influenced by the location of these ferrules.

Keywords: *Ferrule Design, Fracture-Resistance, Post, Core, Restorations, Quartz Fiber Post, Restoration of Endodontically Treated Teeth*

1. INTRODUCTION

Restoration of broken-down and endodontically treated incisors poses a significant challenge in dental practice due to alterations in the mechanical properties of such teeth compared to vital ones. These changes stem from tissue loss due to factors like caries, fractures, or cavity preparations, including the access cavity created before endodontic treatmen[1,2]. The fracture resistance of endodontically treated tooth (ETT) can be improved by minimizing tissue loss and ensuring that a uniform 2-mm ferrule effect is present[3,4]. "Ferrule effect" refers to a band of tooth structure that encircles the circumference of the tooth above the crown-root interface[5]. This effect plays a crucial role in enhancing the fracture-resilience and dislodgement in teeth revived with post and cores. By providing a stable foundation, the ferrule effect reduces the risk of mechanical failure associated with tapered posts or bending forces during post insertion. It also contributes to the marginal integrity of indirect restorations by minimizing the wedging effect[6]. Essentially, the ferrule effect extends the restored crown, acting like a hug around the tooth, thereby preventing root fracture[4,7,8,9,10]. Moreover, it contributes optimal interlocking of cement around the restoration. The ferrule also helps prevent microleakage and subsequent complications, thus ensuring the long-term success of the restoration[7]. In vitro studies have concluded that incorporating ferrules within cores or final crowns can enhance the fracture resistance of restored teeth. This enhancement is achieved by strengthening the external surfaces of tooth to withstand stresses induced by functional lever forces[4].

Maxillary incisors frequently sustain damage[11,12], often due to occlusal overload, which can lead to fractures ranging from the palatal to the facial aspect of teeth, commonly occurring sub-gingivally on the buccal side[13]. Additionally, proximal cavities may leave hard tooth tissue only on buccal and palatal sides.

In these cases, achieving a favorable 2-mm ferrule effect becomes challenging due to the extensive damage and loss of tooth

structure. The limited remaining tooth did not allow a sufficient ferrule.

Studies support the effectiveness of using a ferrule[8,14], achieving a circumferential ferrule (2FR) can be challenging due to the variability of tooth damage. Consequently, incorporating different types of ferrule designs may address these challenges.

A nuanced approach is needed in ferrule design, considering the individual characteristics of each case and prioritizing reinforcement in areas most susceptible to stress. Such tailored approaches can optimize the effectiveness of ferrule design in enhancing the longevity and stability of restored teeth.

Therefore, this in-vitro study investigated fracture resistance of endodontically treated maxillary anteriors restored with fiber-posts, composite cores, and the crown restorations incorporating different ferrule designs.

We explored the clinical relevance of various ferrule designs on fracture-resistance of maxillary anterior teeth treated endodontically restored with fiber post. It aimed to assess the effect of various ferrule designs on fracture-resistance of ETT restored with fiber-posts, cores and crowns.

2. MATERIALS AND METHODS:

The ethical committee of TMDC & RC, Moradabad approved this study (Ref. No. TMDCRC/IEC/21-22/CDE4). We included non-carious teeth with whole root configuration and mature apex, extracted for periodontal reasons. We excluded carious teeth, fractured teeth or teeth with craze lines, and teeth with root resorption

The sample size was calculated on the basis of maximum and least variation in fracture load among the study groups, using the following formula:

$$n = k\frac{\left(z_\alpha + z_\beta\right)^2\left(\sigma_1^2 + \sigma_2^2\right)}{d^2}$$

Where σ1 = 57.89, The minimum SD of fracture load among the study groups

σ2 = 224.81, The maximum SD of fracture load among the study groups[15]

d = max (σ1, σ2), the minimum difference considered to be clinically significant

k = 1.0 the design effect

type I error α = 5% corresponding to 95% confidence level (95%CI)

type II error β = 10% for detecting results with 90% power of study

So the required sample size was n = 14/group

We gathered 56 human upper central incisors that met specific criteria, being free of decay, root canal fillings, restorations, and tooth wear, and having root lengths 11 to 13 mm. **(Fig 1)** To maintain their condition during the study, they were preserved in a 0.1% thymol solution. Subsequently, the teeth were cleaned to remove any hard and soft tissue deposits using an ultrasonic instrument.

In order for ETT to remain functional, a minimum of 5 mm of tooth structure is required above the crestal bone. This includes 3 mm to sustain a healthy soft tissue complex (2 mm of connective tissue and 1 mm of Junctional epithelium), and 2 mm above finish line to ensure structural integrity (axial wall for ferrule effect). To replicate this scenario, the anatomic crowns were removed 3.5 mm above cementoenamel junction (CEJ) and 5.5 mm above the simulated bone level, using a water-cooled diamond stone (Mani-SF11) at 300,000 rpm (NSK air turbine, Japan).

During root canal preparation, a standard master apical file #25 (Mani, Japan) was utilized, WL was set at 1 mm short of apical foramen. Canal shaping was completed using a crown-down technique with rotary nickel-titanium instrumentation. Teeth were instrumented to ISO size 40 apically, and canals dried with paper points.

Teeth were obturated with 0.04 taper ISO No. 40 gutta percha cones using lateral compaction technique, using AH Plus sealer, and temporized. Specimens were then stored in incubator at 37°C for 1 week to ensure complete polymerization. FRC posts were placed 24 h after the completion of root canal treatment followed by obturation

To restore damaged teeth, Angelus Reforpost Fiber Glass was used.

Post spaces were prepared using a Peeso reamer equipped with silicone stops to ensure a minimum 4 mm apical seal. The radial extent of these post spaces matched or exceeded the crown height of the planned restorations. Root canal fillings were eliminated via Peeso reamers (Size 2) driven by an NSK handpiece (1,000–5,000 rpm). Finally, the complete post spaces were finished using manufacturer-supplied drills. **(Fig 2,3)**

Axial Wall Preparation

Group I - No ferrule. All axial tooth structure was eliminated till the shoulder preparation. **(Fig 4)**

Group II - Circumferential ferrule (2FR)

The preparation involved creating a Circumferential ferrule (2FR). The CEJ was marked, and the preparation was made 2 mm above the CEJ to produce a uniform axial wall that was 2 mm in length and 1 mm in width, with a shoulder finish line. **(Fig 5)**

Group III- ferrule in the labial, mesial, and palatal region.

The teeth were prepared as in the 2FR group, but were further reduced on the distal side, providing a 2-mm ferrule on the labial, mesial, and palatal side (group 2FR-LaMPa).

Group IV- ferrule in the labial and palatal region.

Teeth were prepared with 2-mm ferrule on the labial and palatal side. **(Fig 6)**

Mounting of Teeth on Acrylic Blocks

Roots coated with wax 2 mm below the finish line to replicate the biologic width. A 0.25 mm layer of autopolymerizing silicone was applied over the roots to mimic a human periodontium. Subsequently, the teeth were encased in an autopolymerizing acrylic resin, using a surveyor.

Bonding FRC Post and Core Buildup

Root canal walls etched with 32% H_3PO_4 for 15 s, followed by rinsing with a water spray and drying with paper points, compressed air. A bonding agent called Dentsply Prime and bond Universal was used to moisten the dentine, and dual polymerized luting agent (resin) called FluoroCore Dentsply Sirona, was used. A prefabricated quartz fiber post, was inserted in the canal for cementation. Excess material was cleaned, and a quartz-tungsten-halogen unit with a 600 mW/cm^2 light output was held close to the post for 20 s. The remaining tooth structure and posts were then etched for 15 s, and a bonding agent was applied and light polymerized.

Core build-up was performed using prefabricated plastic core formers (Paraform, USA) and resin composite material (FluoroCoreDentsply Sirona, USA), subsequently cured using light polymerization for 40 s. Following this, the core was polished using tapered flat-end bur (FG ISO #025, Shofu) with water irrigation. Subsequently, full metallic crowns measuring 10 mm in height were custom-fabricated using a Ni-Cr alloy.

Glass ionomer luting cement was utilized to cement crowns under a load of 20 N for 10 min. After removing any excess cement, 56 samples were stored in 100% humidity at room temperature for 24 h before testing.

The teeth were exposed to mechanical loading utilizing an angled fixture (jig) in a Universal testing machine, set at a 135° angle relative to the tooth's longitudinal axis. A compression force was applied via a crosshead moving at rate of 1 mm/min until fracture**. (Fig 7)**

Figure 1: Extracted Tooth Sample

Figure 2: Armamentarium for Root Canal Preparation and Obturation

Figure 3: Fibre Post, Composite and Luting Glass Ionomer Cement

Figure 4: No Ferrule Preparation

Figure 5: 2 mm Circumferential Ferrule

Figure 6: 2 mm Ferrule in Labial and Palatal Region

Figure 7: Mechanical Loding on Universal testing machine

Results: All 56 specimens were tested with a universal testing machine set to deliver an increasing load until failure. The variable of interest was the load at failure (**Table 1).**

Table 1: Fracture Strength (N)

S. No.	Group I (0FR)	Group II (2FR)	Group III (2FR-LaMPa)	Group IV (2FR-LaPa)

1	100.22	196.13	255.46	152.98
2	87.27	219.66	236.63	182.89
3	103.54	202.63	259.84	167.93
4	112.81	213.44	263.67	180.44
5	106.75	198.65	245.73	159.23
6	110.47	217.08	249.66	171.27
7	91.43	207.33	241.52	165.42
8	98.35	204.85	257.56	170.06
9	102.63	215.45	254.87	157.53
10	101.87	201.28	266.31	155.45
11	112.23	197.69	235.22	160.28
2	100.55	199.28	268.67	154.23
13	99.45	200.93	251.79	181.98
14	86.27	203.55	231.63	155.76
Mean	**100.98**	**205.56**	**251.32**	**165.38**

Table II: Demonstrates the sample distribution across the different study groups

Group	Description	No of samples
Group I	0FR	14
Group II	2FR	14
Group III	2FR-LaMPa	14
Group IV	2FR-LaPa	14

Table III: Descriptive Summary of Fracture Strength of Included Groups: The Fracture strength of various group materials was evaluated (Table III). The findings demonstrated a significant variation in fracture strength among the tested materials, with Group III exhibiting the highest and Group I the lowest fracture strength.

Group	Fracture Strength (Newtons)					
	Mean	SD	95%CI - Lower	95%CI - Upper	Min.	Max.
Group I (0FR)	100.99	8.35	96.17	105.81	86.27	112.81
Group II (2FR)	205.57	7.77	201.08	210.06	196.13	219.66
Group III (2FR-LaMPa)	251.33	11.81	244.51	258.14	231.63	268.67

Group IV (2FR- LaPa)	165.39	10.62	159.26	171.52	152.98	182.89

The Fracture strength of various group materials was compared using analysis of variance (ANOVA; **Table IV**). The analysis revealed that the Fracture strength significantly varied across the groups, suggesting that the type of material used had a substantial impact on the fracture strength. Tukey's tests were conducted to evaluate fracture strength of various group material pairs (Table 5). The results portrayed significant differences among all pairs of groups ($p<0.001$). The findings highlight the importance of considering the specific material properties when selecting materials for dental applications to achieve optimal fracture strength.

Table IV: Comparison of Fracture Strength of Various Materials

Fracture Strength (N)					
Source	SS	Df	MS	F	p-value
Between Groups	170725.5	3	56908.5	595.4	**<0.001**
Within Groups	4970.2	52	95.6		
Total	175695.7	55			

Table V: Post Hoc Paired Comparisons of Fracture Strength of Various Material Pairs

Group Pair	Fracture Strength (N)		
	Mean Diff.	SE	p-value
Group I vs Group II	104.58	3.70	**<0.001**
Group I vs Group III	150.34	3.70	**<0.001**
Group I vs Group IV	64.40	3.70	**<0.001**
Group II vs Group III	45.76	3.70	**<0.001**
Group II vs Group IV	40.18	3.70	**<0.001**
Group III vs Group IV	85.94	3.70	**<0.001**

A control chart analysis was conducted to illustrate the relative fracture strength of various materials compared to the pooled mean strength of all the materials (Table VI). The mean was compared to the pooled mean. The corresponding findings suggest variations in the fracture strength of different materials, with Group III demonstrating the highest strength, followed by Group II, while Groups I and IV showed comparatively lower fracture strengths relative to the pooled mean.

Table VI: Relative Fracture Strength of Various Materials Compared to Pooled Mean Strength of All Materials

Group	Mean fracture Strength	Pooled mean	95% pooled CI - lower	95% pooled CI - upper
Group I (0FR)	101.0	180.8	165.7	196.0
Group II (2FR)	205.6	180.8	165.7	196.0
Group III (2FR-LaMPa)	251.3	180.8	165.7	196.0
Group IV (2FR-LaPa)	165.4	180.8	165.7	196.0

3. DISCUSSION:

Restoring root canal-treated teeth involves a complex procedure due to multifaceted challenges associated with the tooth's condition, occlusal forces, and various material choices. Preserving tooth tissue, ensuring a ferrule effect, and maintaining proper adhesion are important for thriving long-term outcomes[16,17]. These factors must be carefully weighed against the clinical scenario and dentist needs to select the optimal restorative approach, which may range from direct to indirect techniques utilizing diverse materials such as composites, veneers, or crowns[18]. In this study, maxillary incisors were chosen due to their high vulnerability toward trauma and more angular forces, which may necessitate crown restoration.

A study using finite element analysis[19] compared the stress resistance of intact vital teeth to ETT. Both types of molars experienced damage to the occlusal surface under forces, leading to cusp fractures, albeit at different times[19]. Thus, ETT, regardless of the materials or methods used, have lower strength than healthy teeth because of lost dental hard substance.

In this study, specimens representing restored maxillary anteriors exhibit fracture-resistance influenced by bond strength between prosthetic components (post, core, crown) and residual dental structures, along with the application of force from the palatal direction, simulating lower incisor forces.

In vitro studies[14,20,21,22,23,24,25] have confirmed that a 1.0–2.0 mm ferrule height can significantly increase the fracture strengths of endodontically-treated residual roots. For instance, Singaravelu et al. showed that increasing the ferrule height increases fracture-resistance of teeth samples restored with both custom-made cast post and prefabricated post with metal core, with the maximum fracture-resistance attained at a ferrule height of 2 mm. In this study, a ferrule height of 2 mm was maintained.

This study assessed the resistance of fractures under static loading conditions. The force was administered at an angle of 135°, exceeding the typical 130° contact angle between the upper and lower central incisors. This deviation represented a particularly challenging scenario for evaluating fracture resistance of root canal-treated tooth, which was relevant for surveying the biomechanical performance of fiber-post restorations.

This study indicates that incomplete ferrules can lead to successful restorations, aligning with previous studies[13,15,26]. To enhance the precision of examining the impact of different designs, this study involved groups one with tooth preparation (group 2FR) and another without a ferrule above the cemento-enamel junction (group 0FR). This approach aimed to assess the influence of ferrule design factor more accurately. Among the groups tested, Group 2FR-LaMPa exhibited the highest fracture load, which does not significantly-differ from groups, 2FRLaPa, and 2FR. These results conform with earlier studies[26,27] that employed similar methodologies but varied ferrule designs. Thus, a complete ferrule might not necessarily contribute to the highest fracture-resistance in ETT restored with fiber-posts. Instead, greater fracture-resistance was perceived when palatal ferrule was present, particularly where the load was applied. As a result, the arc of displacement of the complete crown places the remaining root structure under tension, reinforced by the post/core. Thus, the resilience of the root structure itself, rather than the bond between the post/core and the root, is primarily tested when no coronal structure remains.

Existing literature and our results suggest that non-uniform ferrule is more effective than no ferrule. Ng et al.[26] focused on the common clinical scenario where only presence of incomplete ferrule is due to caries process destruction. They concluded that healthy tooth structure is more crucial than 360°-circumferential axial wall dentin in resisting occlusal forces.

Different studies have highlighted that factors like cavity preparations, endodontic treatment, and restorative materials play a crucial role in determining the strength and resilience of teeth.

Some limitations of this study must be noted. The testing method used, a single cycle to failure, does not accurately represent the intraoral conditions where teeth are subjected to mastication in a wet environment with chemical and thermal changes. We focused on a single direction of force and angle, which may not reflect clinical conditions. Additionally, the study simulated maxillary central incisors, limiting the applicability of the results.

4. CONCLUSION:

This study assessed effect of various ferrule designs on fracture-resistance of ETT restored with fiber-posts, cores and crowns. Group 2FR-LaMPa exhibited the highest fracture load, which did not significantly differ from the 2FRLaPa and 2FR groups, but did differ significantly from the 0FR group. Future research should investigate the impact of cyclical loading to closely mimic clinical conditions. A comparison between cast and prefabricated posts and cores may elucidate potential differences.

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