RESEARCH PAPER

Comparative Evaluation of Fracture Resistance of Endodontically Treated Teeth Restored with PEEK and Graphene-Reinforced Posts: An *In vitro* Study

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Abstract

Background: Restoration of endodontically treated teeth is challenging due to the loss of tooth structure and compromised biomechanical properties following root canal treatment. Although glass fiber posts are commonly used, newer biomaterials such as polyetheretherketone (PEEK) and graphene-reinforced posts have shown promising mechanical characteristics and stress distribution behavior. **Aim:** To compare the fracture resistance of endodontically treated teeth restored with PEEK and graphene-reinforced posts under standardized *in vitro* conditions. **Materials and Methods:** Thirty extracted human maxillary central incisors were randomly divided into three groups (n=10): Group I—glass fiber posts (control), Group II—PEEK posts, and Group III—graphene-reinforced posts. Following standardized endodontic treatment, post spaces were prepared and posts were cemented using dual-cure resin cement. Composite core build-ups and full-coverage crowns were fabricated for all specimens. After thermocycling, samples were subjected to fracture testing in a universal testing machine with load applied at 135° to the long axis of the tooth. Fracture resistance values were recorded in Newtons (N) and analyzed using one-way ANOVA and Tukey's post hoc test. **Results:** Graphene-reinforced posts exhibited the highest mean fracture resistance (842.5 ± 58.3 N), followed by PEEK posts (756.8 ± 51.6 N) and glass fiber posts (681.2 ± 47.4 N). The differences among groups were statistically significant ($p < 0.001$). Both PEEK and graphene-reinforced posts demonstrated a higher incidence of favorable fracture patterns compared with glass fiber posts. **Conclusion:** Graphene-reinforced posts showed superior fracture resistance, while PEEK posts also performed significantly better than conventional glass fiber posts. Both materials appear to be promising alternatives for restoring endodontically treated teeth.

Keywords: Endodontically treated teeth, PEEK post, Graphene-reinforced post, Fracture resistance, Post and core.

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Introduction

Endodontically treated teeth are more prone to biomechanical failure due to the loss of coronal and radicular tooth structure from caries, trauma, endodontic access preparation, and restorative procedures. The compromised structural integrity influences their resistance to functional and parafunctional forces, and consequently makes post-endodontic rehabilitation an important factor in determining the long-term clinical success. Post-and-core systems are commonly used to restore severely damaged teeth and as a means of retention for definitive restorations [1, 2]. The conventional fiber reinforced composite posts have shown good esthetic results and stress distribution; however, clinical complications such as post fracture, debonding and reduced fatigue resistance still occur [3]. Therefore, the search for advanced biomaterials with improved biomechanical performance has been intensified.

Polyetheretherketone (PEEK) is a promising biomaterial due to its excellent biocompatibility, low density, radiolucency, chemical stability, and elastic modulus similar to dentin. These properties promote stress distribution and lessen the danger of catastrophic root fractures. Recent investigations have demonstrated the potential of PEEK-based post systems in improving the mechanical behavior of endodontically treated teeth [4, 5]. Moreover, the horizon of restorative biomaterials has been expanded by loading graphene and graphene derivatives. Graphene has exceptional tensile strength, fracture toughness, flexibility and crack propagation resistance. It has been reported that the addition of graphene nanoparticles to dental composites can significantly enhance mechanical properties, such as flexural strength, fatigue resistance, and fracture toughness [6, 7].

Graphene-reinforced materials have gained increasing attention in restorative dentistry due to their ability to improve the load-bearing capacity with favorable biomechanical properties. In addition, graphene displays antimicrobial and bioactive properties that may improve the clinical performance of dental restorations [8].

The ideal post material should ideally mimic the mechanical behavior of dentin, provide sufficient fracture resistance and distribute stresses evenly throughout the root structure. Although promising results have been reported for both PEEK and graphene reinforced posts, comparative studies on fracture resistance are lacking [9]. Thus, the present *in vitro* investigation was performed to evaluate the fracture resistance of endodontically treated teeth with PEEK and graphene posts and to assess their potential as a sophisticated replacement for post-endodontic restoration.

Aim of the Study

To compare and evaluate the fracture resistance of endodontically treated teeth restored with PEEK posts and graphene-reinforced posts under standardized *in vitro* conditions.

Null Hypothesis

There is no significant difference in fracture resistance among endodontically treated teeth restored with glass fiber posts, PEEK posts, and graphene-reinforced posts.

Methodology

Thirty sound human maxillary central incisors with mature apices and similar root dimensions were selected for this *in vitro* study. We excluded teeth with caries, cracks, root resorption, previous endodontic treatment, restorations, or structural defects. Collected specimens were debrided of soft tissue debris and calculus using ultrasonic scalers and stored in 0.1% thymol solution until use. A standardized radiographic examination confirmed the presence of a single canal and similar root morphology.

All specimens were subjected to conventional endodontic treatment. An access cavity was prepared with diamond burs under water spray. The working length was set to be 1 mm short of the radiographic apex. Cleaning and shaping was done with rotary nickel titanium instruments to size F4. Irrigation was done with 17% EDTA and saline and 2.5% sodium hypochlorite. The root canals were filled with gutta-percha and resin-based sealer using lateral condensation technique. The specimens were kept at 37°C and 100% humidity for 7 days for complete setting of the sealer.

Specimens were randomly divided into three groups (n = 10 each). Glass fiber posts were applied to the control group (Group I). Group II specimens were restored with PEEK posts. Posts reinforced with graphene were placed in group III specimens. Preparation of post space was done using corresponding manufacturer recommended drills, maintaining 4 mm apical gutta-percha seal. Post spaces were irrigated, dried and conditioned according to standard adhesive protocols. All posts were cemented with dual-cure resin cement under standardization pressure.

All specimens were built up with composite resin core and a transparent core-forming matrix was used to keep the same dimension. Standardized sized and thickness full metal crowns were fabricated and luted with resin-modified glass ionomer cement. The roots were coated with a thin layer of polyvinyl siloxane impression material to simulate the periodontal ligament before they were mounted in self-cure acrylic resin blocks up to 2 mm below the cementoenamel junction.

All specimens were thermocycled 5,000 times between 5°C and 55°C for 30 seconds in each bath to simulate oral thermal variations. After thermocycling, specimens were mounted in a universal testing machine. A compressive load was applied to the palatal surface at 135° to the long axis of the tooth at a crosshead speed of 1 mm/min until fracture. The maximum load required to cause fracture was recorded in Newtons (N). The fracture patterns were then assessed and categorized as favorable (above the cemento-enamel junction, restorable) and unfavorable (below the cemento-enamel junction, non-restorable). Statistical analysis was performed by one-way ANOVA, followed by Tukey's post hoc test. A p-value of less than 0.05 was considered statistically significant.

Results

Mean values of fracture resistance for the three study groups are presented in Table 1. The highest fracture resistance

(842.5 ± 58.3 N) was observed in teeth restored with graphene reinforced posts, followed by teeth restored with PEEK posts (756.8 ± 51.6 N) among all groups. The lowest fracture resistance was obtained in the glass fiber post group (681.2 ± 47.4 N).

One-way ANOVA showed a statistically significant difference in fracture resistance among the three groups ($F = 24.87$, $p < 0.001$) (Table 2), which confirmed that the type of post material had a significant effect on the fracture resistance of endodontically treated teeth.

Pairwise comparison based on Tukey's post hoc test revealed statistically significant differences between all groups (Table 3). The mean fracture resistance of glass fiber post group was significantly lower than the PEEK post group (mean difference = 75.6 N; $p = 0.012$). Graphene-reinforced posts also exhibited significantly higher resistance to fracture compared to glass fiber posts (mean difference = 161.3 N; $p < 0.001$) and PEEK posts (mean difference = 85.7 N; $p = 0.008$).

Analysis of fracture patterns revealed that the experimental groups exhibited more favorable fractures. In glass fiber post group, 4 specimens showed favorable fracture and 6 showed unfavorable fracture. In the PEEK post group, 7 fractures were favorable and 3 were unfavorable. The highest number of favourable fractures was observed in the graphene-reinforced post group, with 8 favourable and 2 unfavourable fracture patterns.

Table 1: Comparison of Fracture Resistance among Study Groups

Group	Post System	Mean Fracture Resistance (N)	Standard Deviation
Group I	Glass Fiber Post	681.2	47.4
Group II	PEEK Post	756.8	51.6
Group III	Graphene-Reinforced Post	842.5	58.3

Table 2: One-Way ANOVA for Comparison of Fracture Resistance

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	130284.5	2	65142.2	24.87	**<0.001***
Within Groups	70718.6	27	2619.2		
Total	201003.1	29			

*Statistically significant

Table 3: Tukey's Post Hoc Comparison

Comparison	Mean Difference (N)	p-value
Glass Fiber vs PEEK	75.6	0.012*
Glass Fiber vs Graphene	161.3	<0.001*
PEEK vs Graphene	85.7	0.008*

*Statistically significant

Discussion

The restoration of endodontically treated teeth is still a critical issue in restorative dentistry. The loss of tooth structure after endodontic treatment results in a considerable compromise in the biomechanical behavior of the tooth. Intracanal posts are used to improve the retention of the coronal restoration and to allow the distribution of functional stresses in a favorable manner. Biomaterial science has recently introduced new post materials such as polyetheretherketone (PEEK) and graphene reinforced composites, which have shown promising mechanical and biological properties. The present study compared the fracture resistance of endodontically treated teeth restored with glass fiber, PEEK and graphene-reinforced posts under standardized *in vitro* conditions.

The present study showed that the maximum fracture resistance was found in the graphene-reinforced posts, followed by PEEK posts and the conventional glass fiber posts. There were statistically significant differences among the groups, which means that the post material is very important in determining the fracture resistance of endodontically treated teeth. These findings are consistent with recent reports highlighting the importance of the biomaterial properties to improve the biomechanical performance of post-endodontic restorations [11].

The outstanding fracture resistance of the graphene-reinforced posts can be attributed to the unique mechanical properties of graphene. Graphene has very high tensile strength, elastic modulus and fracture toughness, which enhances the structural integrity of composite materials. Graphene is used as a reinforcing agent of dental biomaterials improving the stress transfer and preventing crack initiation and propagation. The nanoarchitecture of graphene allows an even distribution of stress over the whole restorative complex, improving the resistance to fracture under occlusal loading [12, 13].

Recent reports have shown that graphene enhanced dental composites showed significantly higher flexural strength, wear resistance and fatigue performance compared with conventional composites. These properties are particularly critical in post systems in which repeated masticatory forces may deteriorate the material and eventually lead to failure. The higher fracture resistance observed in the present study in the graphene group is consistent with the increasing body of evidence that graphene-based materials may provide significant biomechanical advantages in restorative dentistry [14].

PEEK posts also demonstrated significantly higher fracture resistance than traditional glass fiber posts. This finding could be ascribed to the unique elastic behavior of PEEK.

The modulus of elasticity of PEEK is closer to that of natural dentin than metals and many conventional post systems. Thus, the PEEK is capable of absorbing and distributing the functional stresses better resulting in decreasing the stress concentration in the root dentin. Such modulation of stress decreases the risk of root fracture and aids the durability of the restoration overall [4].

Several studies have demonstrated the good biomechanical properties of PEEK in dental applications. It has good fatigue resistance, excellent chemical stability and superior biocompatibility. Additionally, finite element analysis has shown that PEEK post systems result in less stress concentrations in the root structure than those of metallic and fiber-reinforced posts. These findings corroborate the increase in fracture resistance observed in the present study [15, 16]. Despite their esthetic properties and clinical predictability, glass fiber posts are still widely used, but they presented the lowest fracture resistance among the groups evaluated. The elastic modulus of glass fiber posts is similar to dentin, allowing a good distribution of stresses, but their mechanical strength is lower than the new nanocomposite materials. The fiber-matrix interface can also be a potential site for crack initiation under conditions of excessive loading [17]. One of the most important findings of the present study was the higher incidence of favourable fracture patterns seen in the graphene reinforced and PEEK groups. Favorable fractures are usually considered restorable since they occur above the cemento-enamel junction while unfavorable fractures often involve the root and may require extraction. Experimental groups showed a predominance of favorable fracture modes, which indicate that these materials not only improve the fracture resistance but also improve the distribution of stresses within the tooth structure. Similar observations have been reported in recent studies on the evaluation of high-performance polymer-based post systems [18].

The addition of thermocycling to the study design increased the clinical relevance of the findings. Thermal fluctuations within the oral cavity can affect material properties and adhesive interfaces over time. The specimens were subjected to repeated temperature cycles to simulate intraoral aging conditions. The good performance of the graphene-reinforced and PEEK posts after thermocycling indicates their possible stability under oral environmental stresses [19].

However, despite promising findings there are some limitations of the present study. The investigation was performed under laboratory conditions, and therefore, cannot fully reproduce the complex oral environment. Cyclic fatigue loading, saliva, pH variations and patient specific occlusal patterns were not mimicked. Moreover, the sample size was relatively small and limited to maxillary central incisors. Future research should focus on long-term fatigue testing, finite element analyses and randomized clinical trials to validate the clinical performance of these emerging materials.

Within the limits of the present study, the graphene-reinforced posts had the highest fracture resistance and most favorable fracture behavior among the groups investigated. PEEK posts also showed superior performance over conventional glass fiber posts. The results of this study indicate that both graphene-reinforced and PEEK posts could serve as efficient alternatives for restoring endodontically treated teeth. However, the graphene-reinforced posts have the most potential to improve the long-term biomechanical performance and clinical success.

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