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Evaluation of Fracture Resistance and Failure Modes of Maxillary Premolars Restored with Different Coronal Designed Fiber Posts: *In Vitro* Study

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ABSTRACT

Objective: The design and structural properties of fiber posts play a crucial role in the long-term success of endodontically treated teeth by influencing their fracture resistance and failure patterns. This study aimed to evaluate the effect of fiber posts with different coronal designs on fracture resistance and failure mode in endodontically treated maxillary premolars restored with cusp-covering direct overlay restorations.

Methods: Forty-five extracted human maxillary premolar teeth were selected. The 2 mm cusp reducted MOD cavity preparations and root canal treatments were performed. The teeth were divided into three groups (n=15): group 1: standard conical post (SCP) (Exatec Blanco HT-glass fiber post), group 2: cylindrical core post (CCP) (Exatec Blanco HT-glass fiber post) and group 3: control group (no post applied). After the placement of posts, overlay restorations were made with resin composite. The fracture resistance test was applied with a universal testing device and maximum forces were recorded. The failure mode scores were recorded using a dental microscope. The ANOVA test was used for the statistical analysis ($p<0.05$).

Results: While no significant difference was observed in terms of fracture resistance between SCP and CCP groups (1033.15 N and 981.17 N, respectively), the control group had significantly lower fracture resistance (852.93 N) ($p=0.004$). The number of restorable failure modes was higher in all groups. The non-restorable failure mode V was higher in CCP and control groups than SCP group.

Conclusion: Different coronal designs of fiber posts showed no significant difference in fracture resistance. Restorable failures were more frequent in the SCP group.

Keywords: Cusp coverage restoration, endodontic treatment, failure mode, fracture resistance, glass fiber post

HIGHLIGHTS

- The fracture resistance of endodontically treated maxillary premolars was significantly improved with fiber post placement, compared to the control group without posts.
- Cylindrical core fiber posts did not provide superior fracture resistance compared to standard conical posts, despite their larger coronal volume.
- Both post designs predominantly exhibited restorable failure modes, reinforcing the clinical relevance of fiber post systems in preserving tooth structure after fracture.

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INTRODUCTION

Endodontically treated teeth have a risk of fracture during function compared to a vital tooth (1) due to caries, trauma, endodontic access preparation (2) or changes in the physical properties of radicular dentin resulting from irrigation solutions and medicaments (3). In addition, loss of proprioception due to loss of pulpal nerve tissues contributes to the risk of fracture (4). It has been reported that the highest risk of tooth fracture is in endodontically treated teeth with mesio-occluso-distal (MOD) cavities, where both marginal ridges are lost (4). Intracanal post and core systems are needed for the retention of the coronal restoration in such teeth to ensure the long-term success of the restoration (5).

The retentions of posts are classified as metallic and non-metallic (6). Since metal posts cause high stresses and root fractures that are usually unrestorable, fiber posts with esthetic and mechanical properties similar to dental tissue have been developed (7). Fiber posts consist of carbon or glass fibers stretched in a polymeric resin matrix (8) and have been reported to reduce the risk of radicular fracture (9) due to their elastic modulus being closer to dentin (10). The use of glass fiber posts with composite resin core base materials for coronal restoration after root canal treatment is widely accepted (11). Glass fiber posts reduce the stress at the interfaces under force, allowing the restoration to mimic the mechanical behavior of a natural tooth (12).

The placement of fiber posts into the root canal system and their restorative success are directly associated with their effects on mechanical stress distribution. Finite element analysis studies have evaluated the influence of different post designs on fracture resistance and stress distribution. These studies have shown that prefabricated posts lead to higher stress concentration in the cervical region (13, 14). However, further research is needed to determine the clinical relevance of these findings.

In most of the studies, posts with a taper or cylindrical shape throughout the post integrity were used, and it was found that the results varied when fracture resistance and restorability were evaluated (15, 16). It has recently been demonstrated that the design of the prefabricated post head also affects the stress distribution within the core and crown structure (17). Considering this situation, the durability of endodontically treated teeth is affected by the post-core design as well as the material used (18).

The cylindrical core design of Exatec Blanco HT-Glass fiber posts (Hahnenkrat, Königsbach-Stein, Germany) differs from conventional conical post designs by having a cylindrical core shape at the coronal part and a conical post shape at the root canal part. The rounded retainers at the head region support bonding with the composite and act as a preventive mechanism against rotation. The spiral grooves at the apex provide decompression and retention (19). It has been stated that the larger coronal volume of the post covers a larger area, especially in the cavities of teeth with more coronal damage, thus saving both the amount of the composite material to be used for restoration and the time (20).

Previous studies have shown that fiber posts increase fracture resistance (16, 21); however, there is insufficient evidence on the effects of different coronal designs on fracture resistance and failure modes. The aim of this study was to evaluate the fracture resistance and restorability of different coronal-designed fiber posts on maxillary premolars restored with cusp-covering direct overlay restorations. Our hypothesis was that different fiber post designs would not make a significant difference on fracture resistance. Testing this hypothesis will provide clinicians with a scientific basis on which post design is more advantageous in increasing restorative success.

MATERIALS AND METHODS

The Ethical approval of this study was obtained from the Firat University Non-interventional Ethics Committee (process no. 2024/04-03), following the principles and guidelines of the Declaration of Helsinki for medical research involving human subjects. According to a previous study, the minimum sample size required to detect a significant difference should be at least 10 in each group, considering type I error (alfa) of 0.05, power (1-beta) of 0.9, and effect size of 0.82 (WSSPAS; Web-Based Sample Size & Power Analysis Software (22)). Fifteen teeth per group (45 in total) was established for the present study.

Sample Selection

Single-rooted maxillary premolar teeth extracted for periodontal or orthodontic reasons, with a root curvature of less than 10°, a single root canal and a length between 21 and 23 mm were selected for the study. Teeth were collected from patients whose teeth were extracted at the Oral and Maxillofacial Surgery department of Firat University. Teeth with caries, crown or root fracture or microcracks, previously undergone endodontic treatment or restorative procedures, root resorption, lateral canals and root curvature >10° were excluded from the study. All teeth were examined with cone-beam computed tomography (Planmeca ProMax 3D Mid, Helsinki, Finland) to assess root integrity, root canal shape and the number of available root canals. To standardize the procedures and samples, 45 teeth with a root length of 14±1 mm (23) and a buccolingual/mesiodistal ratio of 1.6 were selected. Soft and hard tissue residues were removed from the teeth using a curette. All teeth were kept in 0.5% Chloramine-T solution at 4°C for 15 days and then stored in pure water until the day of the experiment.

Root Canal Treatment and Cavity Preparation

The same operator performed all procedures. Before the cavity preparations, the original crown impressions of teeth were taken with silicone impression material for the subsequent overlay restoration (24). A standard access cavity was prepared with a diamond round bur for root canal treatment. Working length was determined with 10# K files (VDW, Munich, Germany), and 1 mm behind the length where the file appeared in the apical foramen was taken as the reference working length. The root canals were prepared with WaveOne Gold (Dentsply Sirona, Ballaigues, Switzerland) 20/07, 25/07 and 35/06 files, respectively, using VDW silver endo motor (VDW). After each file, the root canals were irrigated with 2 ml of 5% NaOCl (Wizard Guide Chemistry, Istanbul, Türkiye). For final irrigation, 4 ml of 5% NaOCl, 5 ml of 17% EDTA (Imicryl, Konya, Türkiye) and 5 ml of distilled water were used. The root canals were dried with sterile paper points (Dentsply Maillefer, Baillaigues, Switzerland). The root canals were filled with resin-based AH Plus root canal sealer (Dentsply, De Trey, Konstanz, Germany) and WaveOne Gold 35/06 gutta-percha (VDW) using the single-cone method. Temporary fillings were placed and the teeth were kept at 37°C and 100% humidity for 1 week. After the temporary fillings were removed, the standardized MOD cavity de-

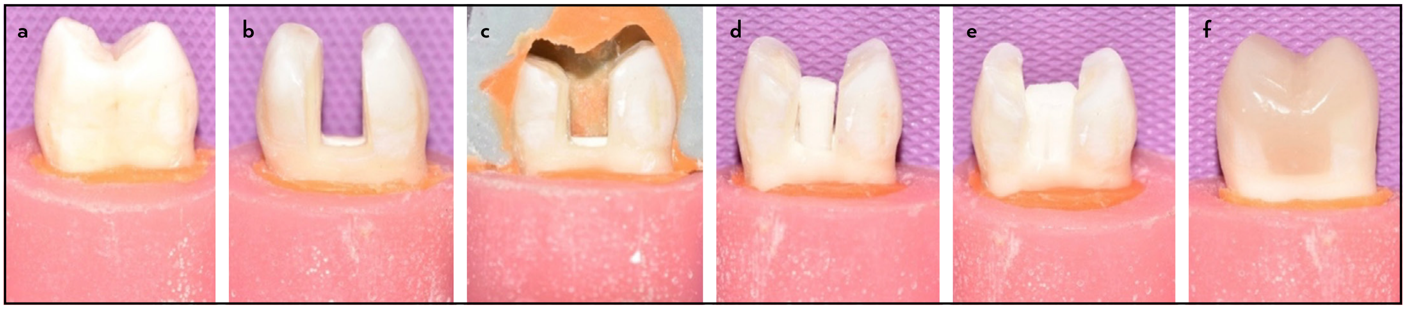

Figure 1. Representative images of specimen preparation. (a) Proximal view of intact tooth, (b) mesio-occluso-distal cavity preparation and access opening, (c) 2 mm buccal and lingual anatomical cusp reduction, (d) standard conical post placement after root canal treatment, (e) cylindrical core post placement after root canal treatment, (f) cusp-covering direct overlay restoration with composite resin

sign defined by Mergulhao et al. (25) was performed with endodontic access cavity modification (Fig. 1b). 2 mm buccal and lingual anatomical cusp reductions were performed (Fig. 1c). The teeth were randomly divided into three groups (n=15).

Group 1: Standard conical post (SCP)

Exatec Blanco HT-Glass Fiber (Hahnenkratt, Königsbach-Stein, Germany) SCP system drills (42 010, 43 000, 42 100 and 42 005) (Hahnenkratt) were used in order according to the manufacturer's instructions (Fig. 2a). Root canals were prepared by creating a 10 mm post space in the root using post drills sequentially. 37% orthophosphoric acid (Ruby Etch; İnci Dental, Istanbul, Türkiye) was applied to the root canal system and access cavity surface for 15 seconds, rinsed for 10 seconds and dried with paper points (26). Clearfil Universal Bond Quick ('C-UBq'; Kuraray Noritake, Tokyo, Japan) was applied in two layers with a brush and spread by air into the root canal. After the bond material was removed with air, the excess bond in the root canal was removed with a paper point and cured with Woodpecker LED D Light Cure Unit (Woodpecker, Muenster, Germany) for 40 seconds (s). The post was placed in the post space about 10 mm long at the root (Fig. 3) using RelyX U200 Automix dual cure resin cement (3M, Maplewood, MN, USA) and polymerized for 40 s (Fig. 1d). The apical diameter and coronal top-level diameter of the post were 0.98 and 1.8 mm respectively. To facilitate coronal restoration, silicone guides taken before preparation were divided into two mesial and distal parts and Clearfil Majesty Posterior (Kuraray, Okuyama, Japan) composite resin was applied and cured for 20 s for each layer according to the manufacturer's instructions to complete the overlay restoration (Fig. 1f).

Group 2: Cylindrical core post (CCP)

The same procedures were performed as Group 1. The drills of CCP group (42 010, 43 000, 42 100 and 42 003) (Hahnenkratt) were used sequentially in order according to the manufacturer's instructions (Fig. 2b). The CCP system was used for post placement (Fig. 1e). The apical diameter and coronal top-level diameter of the post were 0.98 and 2.8 mm respectively. The post length was adjusted to have the same length in Group 1 (Fig. 3).

Group 3: Control

Direct composite overlay restorations with silicone guides were performed after root canal treatment as specified in group 1.

All roots were dipped into the melted wax and embedded in auto-polymerized acrylic blocks. After the acrylic polymerization, the teeth were separated from the blocks. The wax remnants were removed from acrylic and teeth to mimic the periodontal ligament. Silicone impression material (Zetaplus, Zhermack SpA, Italy) was injected instead of the removed wax and the excess impression material was removed using a lancet. The simulated periodontal ligament thickness was 0.20–0.30 mm (27). The reason for choosing acrylic resin is to ensure that the samples remain stable during mechanical testing and to minimize deformation.

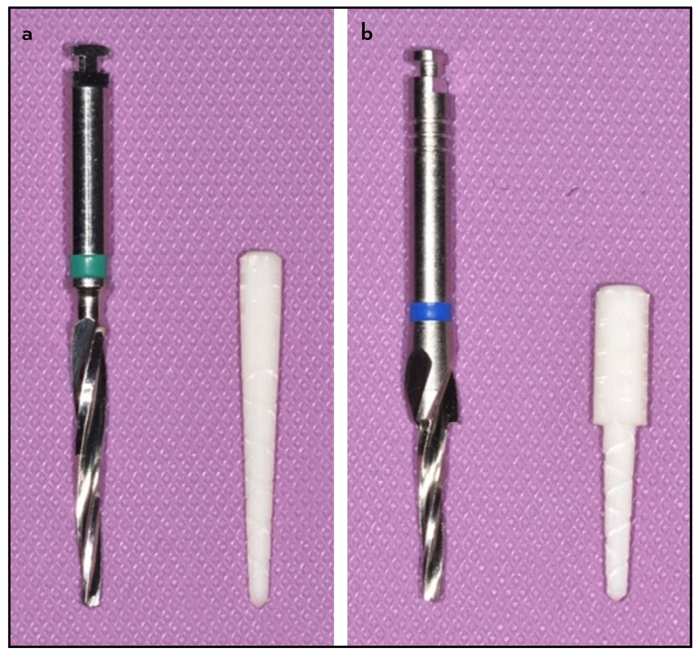

Figure 2. Images of; (a) standard conical post (right) and final post drill (left), (b) cylindrical core post (right) and final post drill (left)

Fracture Resistance Test

Acrylic blocks were fixed to the universal testing machine (AG-X Shimadzu, Kyoto, Japan) and subjected to a universal testing machine with a 5 mm diameter piston parallel to the long axis of the teeth and in contact with the palatal surface of the buccal tubercle and the buccal surface of the palatal tubercle. The crosshead speed was 5 mm/min. The load was applied until the teeth were fractured and the maximum force for each sample was recorded in Newton (N). The failure mode of the tested samples was scored using a dental microscope (Zumax oms2360, Suzhou New District, China) as described in a previous study (Table 1) (28).

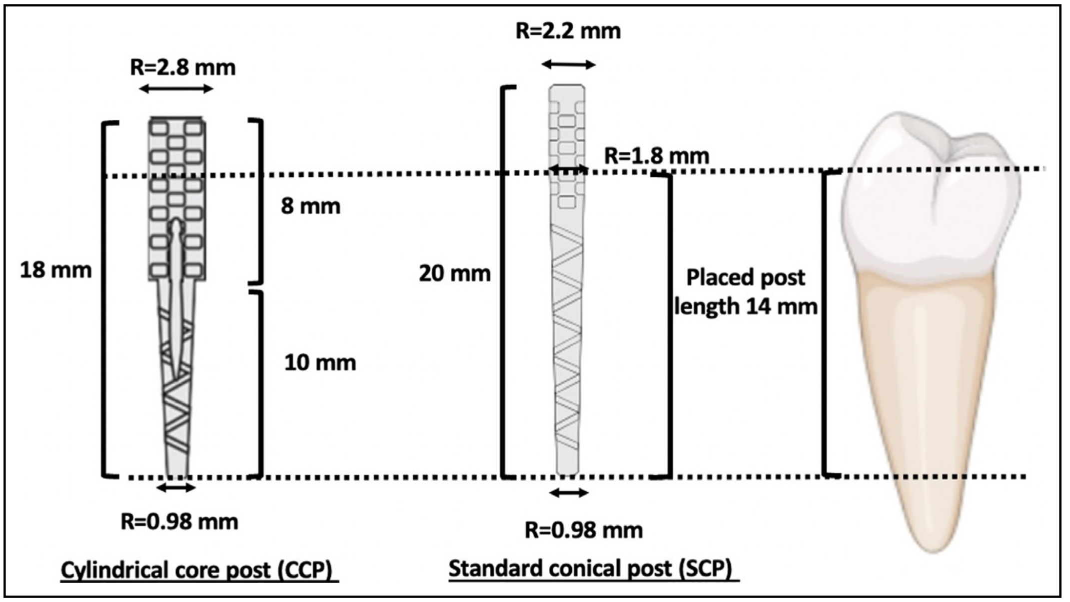

Figure 3. Images of cylindrical core and standard conical posts' apical and coronal diameters, lengths and a view of placed post length

Data Presentation and Statistical Analysis

Statistical tests were performed using SPSS for Windows, Version 26.0 (IBM Corp., Armonk, NY). Since the data distribution was normal according to the Shapiro-Wilk test and the variances were homogeneously distributed, ANOVA and post hoc Tukey tests were used to evaluate the data. The cut-off level for significance was set at α=5%.

RESULTS

The mean, standard deviation (SD) and minimum-maximum values of the fracture resistance of the groups were indicated in Table 2. The data of the failure modes were indicated in Table 3. The mean fracture resistance values of the SCP and CCP groups were 1033.15 N and 981.17 N, respectively, no statistically significant difference was found between the groups (p>0.05) (Fig. 4). The mean fracture resistance value of the control group was 852.93 N and showed a significantly lower fracture resistance than the other experimental groups (p=0.004).

Although except VI, all failure modes were observed at least once in each group, they were generally distributed similarly in all groups. The most common failure mode was V in all groups, it was higher in CCP and control groups than in the SCP group. In all samples, the total restorable failure modes (I, II, III and IV) was observed to be higher than the total non-restorable failure modes (V and VI) (Fig. 5).

DISCUSSION

In this study, the fracture resistance and failure mode of fiber posts with different coronal designs on maxillary premolar teeth with overlay restoration were evaluated. SCP and CCP

TABLE 1. Fracture mode classification

Failure mode	Fracture pattern	Restorable/ non-restorable
I	Fractures were limited to restoration	Restorable
II	Fractures were less than half of the crown and did not extend to root	Restorable
III	Fractures were more than half of the crown and did not extend to root	Restorable
IV	Crown fractures extended to root, extension was less than 2 mm above acrylic line and can be restored	Restorable
V	Crown fractures extended to root, extension was more than 2 mm below acrylic line and cannot be restored	Non-restorable
VI	Fractures were limited to root.	Non-restorable

TABLE 2. The data of maximum fracture resistance values (Newton) (n=15)

Groups	Mean	SD	Min	Max	F	p
SCP[a]	1033.15	131.31	872.01	1384.42		
CCP[a]	981.17	142.44	726.35	1174.37	6.232	0.004
Control[b]	852.93	156.82	610.93	1161.4		

*: The letters indicate the comparison among the groups. The same letter indicates no difference between groups. SD: Standard deviation, SCP: Standard conical post, CCP: Cylindrical core post

TABLE 3. Distribution of failure modes (n=15)

Groups	Failure modes					
	I	II	III	IV	V	VI
SCP	2	3	2	3	5	-
CCP	2	2	2	2	7	-
Control	2	2	1	3	7	-

SCP: Standard conical post, CCP: Cylindrical core post

groups did not show any significant difference in terms of fracture resistance. Therefore, sufficient evidence was not found to reject the hypothesis.

Maxillary premolar teeth have a high fracture incidence due to their complex anatomy, low cervical thickness and concavity in the mesial surface of the root (29). Such teeth can be easily fractured, especially after root canal treatment, with the complete loss of the marginal ridge and removal of the pulp chamber (24). It has been reported that in the inlay cavity preparation where the cusps are preserved, they should be reduced by at least 1.5 mm due to the possibility of fracture of the thin cusp structures (30). Therefore, in the current study, cusp coverage overlay restoration was performed after MOD cavity preparation on maxillary premolar teeth and the cusps were reduced by 2 mm.

In previous studies evaluating the fracture resistance of maxillary premolar teeth with MOD cavities, different types of forc-

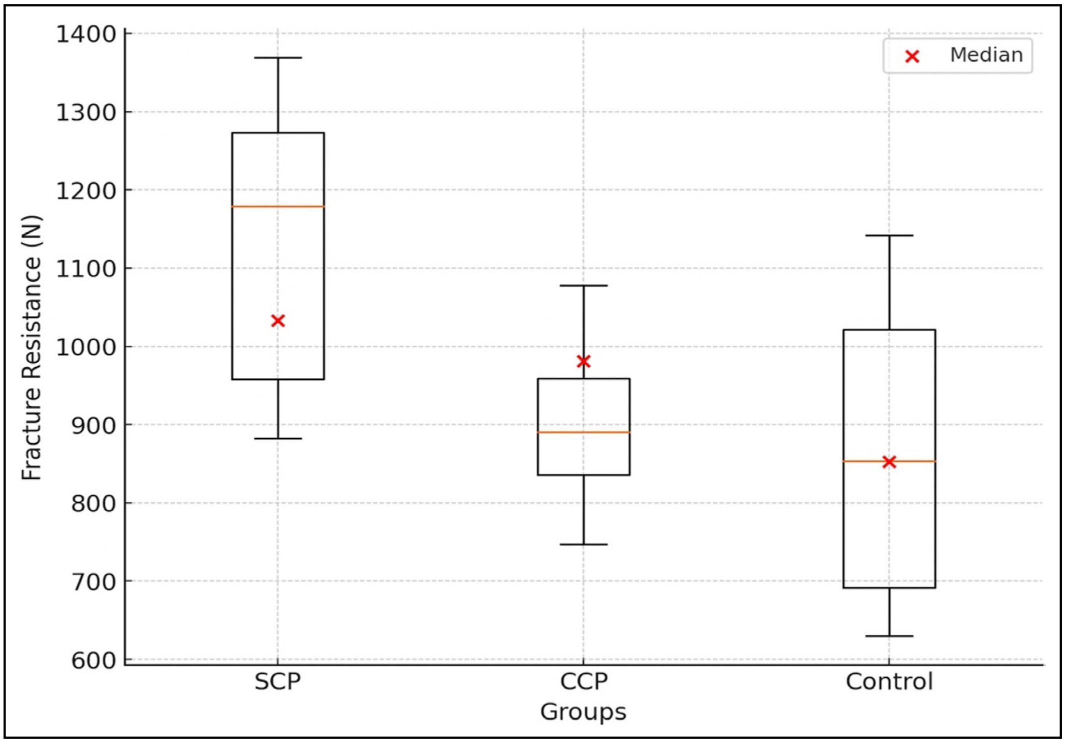

Figure 4. Box plot of minimum, maximum fracture resistance values of groups

SCP: Standard conical post, CCP: Cylindrical core post

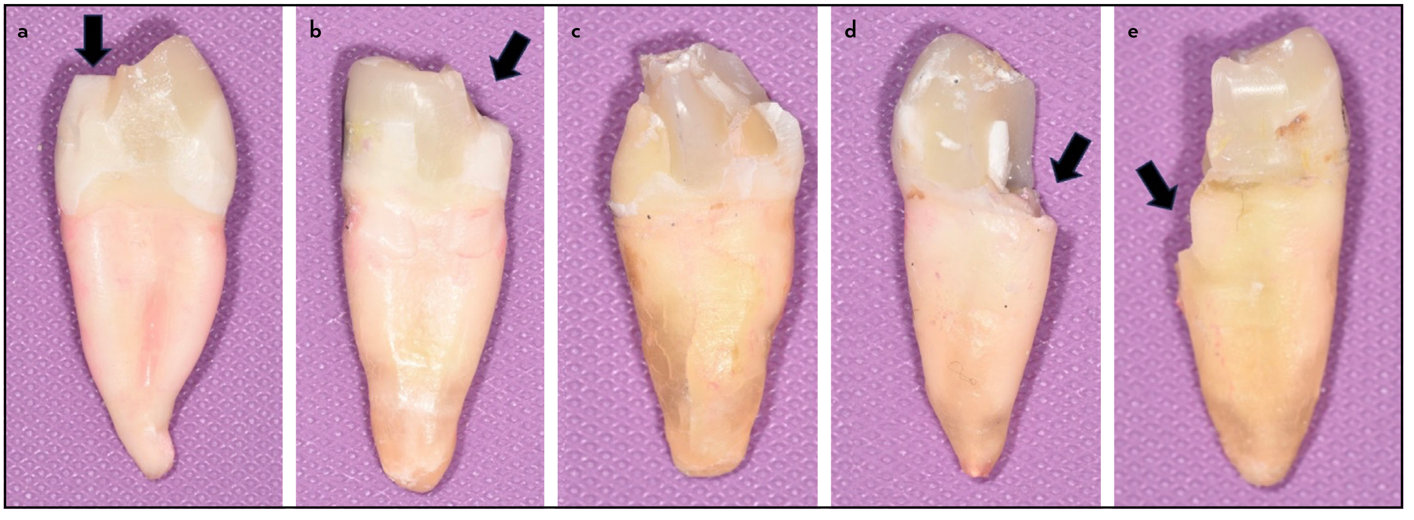

Figure 5. Representative images of different failure modes. (a) mode I; (b) mode II; (c) mode III; and (d) mode IV, (e) mode V

es were applied (24, 31). Intraoral forces consist of static and repetitive movements and do not cause fractures under normal conditions (24). While anterior teeth are mostly exposed to shear and lateral forces, posterior teeth are mostly exposed to vertical forces (32). Therefore, in the current study, a fracture resistance test was applied to the teeth under vertical forces. In studies, silicone impression material was used to absorb the applied vertical forces to mimic the periodontal ligament, which reduces occlusal forces (33). Therefore, silicone impression material was used to mimic the periodontal ligament in our study.

It has been stated that the prognosis of teeth with root canal treatment depends not only on the root canal treatment but also on the material and technique used to restore the coronal cavity appropriately (34). In this context, different materials and restorative techniques have been used to increase the therapeutic success of teeth with extensive coronal damage (35, 36). The use of post-core restorations has been recommended, especially in cases where 50% or more of the posterior tooth crown wall has been lost (37). In studies evaluating the fracture resistance of post-retention composite restorations (23, 33), it has been stated that the monoblock dentin post-core structure provides better results by providing a more even distribution of applied forces along the root (31).

In addition to the material used in the success of posts, it has been emphasized in many studies that post designs are also effective (18, 38). In the present study, glass fiber posts with different coronal designs were evaluated in experimental groups. The SCP and CCP groups (981.17 N and 1033.15 N) showed more fracture resistance than the control group (852.93 N) ($p=0.004$). In previous studies, the fracture resistances of restorations with or without posts in maxillary premolars were evaluated (16, 18, 21, 39). Nothdurft et al. (16) investigated the effects of direct composite restorations and different types of posts on the fracture resistance of endodontically treated mesio-occlusal cavity designed premolars and reported that the groups with posts increased the fracture resistance compared to the group with only composite restoration. Sorrentino et al. (18) and Siso et al. (39) used maxillary premolar teeth with MOD cavity design, they supported the effect of post placement in addition to composite restoration on teeth. Furuya et al. (21) reported that the fracture resistance of the groups without fiber posts was lower than that of groups with posts in teeth with full cusp coverage restorations in maxillary premolars. These results support the findings of our study, showing that the fracture resistance increased when fiber posts of different designs were used in addition to composite restorations.

On the other hand, Soares et al. (40) reported that the fracture resistance of the post group decreased significantly compared to the group without post. In their study, they applied force at a 30° angle on mandibular premolars with composite restoration and MOD cavity. In addition, they emphasized that the main purpose of posts in root canal treated teeth with excessive material loss is to ensure the retention of the restorative material and not strengthen the tooth structure (40). These results contradict the data of the current study. These different findings may be due to the teeth used in the methodologies of other studies, cavity designs, and the load and angle differences applied to the teeth.

There was a larger volume core structure in the CCP group. In our study, although there was no significant difference in fracture resistance between the CCP and SCP groups ($p>0.05$), the CCP group showed lower fracture resistance values. To our knowledge, there is no other study comparing fracture resistance of CCP design post-core restorations in the literature. In a study conducted by Trabert et al. (41), the fracture resistance of posts with different coronal diameters was assessed. They stated that the large diameter posts showed lower resistance to fracture compared to small diameter posts and this situation was associated with the decrease in the amount of remaining dentin in teeth restored with large diameter posts (41). In our study, there was more preparation in the cervical part of the tooth in the CCP group due to the drill and post design (Fig. 3). Therefore, since the cervical substance loss was greater, the fracture resistance may have yielded lower results. In other words, the amount of dentin removal required for post placement may also contribute to variations in fracture resistance and failure modes across studies.

It is important for the remaining dental tissue to survive in a restorable manner after a tooth fracture. The number of teeth that can be restored in all groups is generally higher than in non-restorable failure modes. It has been reported that the composite resin can absorb the loading force before passing through the tooth structure in a tooth with cusp coverage restoration (42). Therefore, it can be considered that the total number of restorable failure modes was higher than non-restorable failure modes in all groups. It has been stated that conical posts concentrate the tensile stress in the cervical region of the root by creating a wedge effect, resulting in stress concentration in the coronal part of the root and lower retention (43). In the CCP group, the fact that the base of the cylinder shape is located on the cavity floor can be considered that the failure mode V can be prevented by reducing the wedge effect. However, according to the findings of our study, type V was the highest failure mode in the CCP and control groups. In the CCP group, this situation may be related to the additional dentin preparation in the cervical region. In this post design, while the cylindrical core diameter was 2.8 mm, the approximate diameter of the post corresponding to the cervical was 2.2 mm in the SCP group (19) (Fig. 3). Since this volume difference may cause the removal of excess tooth tissue in the cervical region of the root to form the core socket, the non-restorable failure may have been found higher than the SCP group.

It has been stated that the absence of a post to distribute the stress along the tooth root and the concentration of applied force in the cervical and coronal thirds of the root may lead to more irreparable failure (44). Similar to the findings in our study, the study by Chitkraisorn et al. (44) produced more restorable fractures in the groups with posts. They explained this difference by the uniform stress distribution in the teeth restored with posts, which was similar to the elastic modulus of radicular dentin. Within the scope of these findings, the use of post restoration in teeth with crown damage may be advantageous in terms of stress distribution.

The findings of this study highlight the importance of post-core system selection in restoring endodontically treated maxillary premolars with significant coronal damage. The results suggest that additional cervical dentin removal for CCP may impact long-term outcomes by increasing non-restorable failure modes. These results reinforce the clinical benefit of fiber posts in enhancing structural integrity and achieving predominantly restorable fractures, which is essential for ensuring the longevity and predictability of direct composite restorations in posterior teeth. Although there was no significant fracture resistance difference between the different coronal-designed fiber post groups, the fracture modes are different from each other in this study. Therefore, not only mechanical strength but also factors related to clinical practice, such as restorability after fracture should be considered in post selection.

This study had the following limitations: physiological occlusal forces could not be simulated for the fracture of teeth and only vertical force was applied. The experiments could not simulate oral conditions such as thermal change. These factors could potentially affect the fracture resistance and failure patterns of restored teeth. However, all experiments were conducted under the same standard conditions allows the materials to be compared with each other. More *in vitro* studies simulating oral conditions and clinical studies are warranted to increase the clinical significance of these findings and optimize post-core designs for long-term clinical success.

CONCLUSION

Within the limitations of this *in vitro* study, the findings demonstrated that the use of CCP and SCP significantly enhanced the fracture resistance of endodontically treated maxillary premolars with cusp-covering direct overlay restorations compared to the control group without posts. While both post designs provided comparable fracture resistance, the cylindrical core post design did not yield superior outcomes despite its larger coronal volume. Notably, both post designs primarily resulted in restorable failures, reinforcing their clinical relevance in preserving tooth integrity under functional loads. However, the additional dentin preparation required for CCP may contribute to higher non-restorable failure rates. Therefore, its use should be carefully considered, particularly in cases where dentin preservation is a priority.

Disclosures

Ethics Committee Approval: The study was approved by the Firat University Non-interventional Ethics Committee (no: 2024/04-03, date: 03/05/2024).

Authorship Contributions: Concept – T.G., E.D., A.G.; Design – T.G., E.D., M.R.A., A.G.; Supervision – T.G., A.G.; Funding – T.G., E.D.; Materials – E.D., M.R.A., FK.; Data collection and/or processing – E.D., M.R.A., FK.; Data analysis and/or interpretation – T.G., A.G.; Literature search – T.G., E.D.; Writing – T.G., E.D.; Critical review – T.G., A.G.

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