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Fracture Resistance of over Flared Endodontically Treated Central Incisors Restored with Multiple Prefabricated and Custom-Made Glass Fiber Posts

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ABSTRACT

Objectives: This study aimed to evaluate the fracture resistance of over flared endodontically treated bovine central incisors restored with prefabricated and custom-made glass fiber posts, using the multi-post approach.

Materials and Methods: Sixty-eight crownless over flared endodontically treated incisors were used for this study. The depth of prepared post space was 10 mm, and the remaining dentin thickness of the roots was 1 mm. The samples were randomly divided into four groups (n=17): Group 1: two prefabricated glass fiber posts; group 2: prefabricated glass fiber post + braided glass fiber; group 3: braided glass fiber; group 4: no post. Static load was applied at a crosshead speed of 0.5 mm/min at 135º angle relative to the root longitudinal axis until fracture. The data were analyzed using one-way ANOVA and post hoc Tukey's test at a significance level of P<0.05.

Results: Groups 3 and 4 exhibited the maximum (981 N) and minimum (461 N) fracture strength values, respectively. The differences between group 4 and other groups were significant (P<0.001), but the differences between groups 1, 2, and 3 were not significant (P>0.05).

Conclusion: Multiple prefabricated and custom-made glass fiber posts significantly increased the fracture resistance of crownless endodontically treated central incisors with over flared root canals.

Keywords: Tooth Fractures; Root Canal Therapy; Post and Core Technique

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INTRODUCTION

The decision on how to reconstruct endodontically treated teeth with extensive coronal destruction has always been a significant challenge in restorative dentistry [1]. A decrease in the biomechanical properties of endodontically treated teeth because of extensive coronal destruction necessitates the use of posts to increase the coronal restoration's strength and retention [2]. A previous study on structurally compromised endodontically treated teeth (without ferrule) restored with different post and core systems indicated that metal post and core had higher fracture resistance than fiber post but resulted in stress concentration in the middle and apical thirds of the root, leading to unfavorable fractures [3].

The role of fiber-reinforced composite resins in increasing the fracture resistance of coronal

restorations has been evaluated [4-6]. Currently, fiber posts have attracted the attention of clinicians due to their biomechanical properties that are similar to those of dentin, their ability to distribute stresses homogeneously, reducing the risk of irreversible root fractures [7], and their long-term clinical performance [8,9]. It has been demonstrated that the low elastic modulus of fiber posts results in the concentration of stresses predominantly on the cervical area, leading to debonding of the post [10] and failure of the restoration at the core area [2].
In some cases, the root structure of the tooth is compromised due to caries, trauma, pulpal pathologies, or iatrogenic factors during root canal treatment, resulting in poor long-term prognosis of the tooth-restoration complex due to increased risk of root fracture [11-13]. Various techniques have been introduced for the reconstruction of crownless endodontically treated teeth with over flared root canals, including the reinforcement of root canal with composite resin, use of bonded fibers, fabrication of anatomical posts directly or indirectly, and recently, the use of accessory fiber posts using multi-post approach [14-16]. Due to the contradictory results of different studies, it is difficult to express a definite opinion about these techniques. Although some studies indicated no significant difference in fracture resistance between multiple post technique and single fiber post or cast metal post [17,18], it appears that the multi-post approach results in a more favorable fracture pattern compared with placement of a single post, in addition to the advantage of saving time [17].
Glass fiber posts are the most widely used non-metal posts in dentistry due to their high flexural strength, modulus of elasticity similar to dentin, and reasonable cost [19,20]. In addition to differences in composition compared with other fiber posts, there are differences in shape and physical structure (geometry) between glass fiber posts (i.e., prefabricated cone-shaped and custom-made braided posts), resulting in different performance in different situations, depending on their physical structure [21]. The differences mentioned above led to conduction of various studies on the fracture resistance of endodontically treated teeth [22,23].
Considering the importance of successful reconstruction of endodontically treated teeth with extensive coronal destruction and over flared root canals, the possible differences in the performance of various shapes of fiber posts in the outcome of treatment [20] and contradictory results of studies on the efficacy of the multi-post approach, the present study aimed to evaluate the fracture resistance of crownless over flared endodontically treated bovine central incisors restored with multiple prefabricated and custom-made glass fiber posts.

MATERIALS AND METHODS

Table 1 presents the characteristics of the materials used in the present study. The extracted bovine maxillary central incisors were stored in phosphate buffered saline (Medicago AB, Uppsala, Sweden) until use [24].
After visual examination at ×4 magnification for cracks and fractures, radiographic examinations were carried out from the buccolingual and mesiodistal directions to select teeth with similar internal root canal anatomy, without curvature and internal resorption. Finally, 68 sound incisors with similar internal anatomy and size in terms of length and width were selected. The teeth were sectioned 14 mm above the root apex with the use of a diamond saw (Diaswiss, Geneva, Switzerland) at low speed under water coolant, leaving no ferrule [11]. The step-back technique was used to prepare the root canals with stainless steel K-files (Dentsply Maillefer Instruments SA, Ballaigues, Switzerland) and #4, #3, and #2 Gates-Glidden drills (Mani, Tokyo, Japan), using 1% NaOCl as irrigating solution.
The root canals were obturated with gutta-percha and AH26 sealer (Dentsply, Konstanz, Germany) using the lateral compaction technique.

Table 1. Characteristics of the materials used in this study

Material	Composition	Manufacturer
Exacto	87% glass fiber, 13% epoxy resin	Angelus, Londria, PR, Brazil
Interlig	Glass fibers—60±5% impregnated with 40 ± 5% resin containing Bis-GMA, diurethane, barium glass	Angelus, Londria, PR, Brazil
Duo-Link	BIS-GMA, TEGDMA, UDMA, 62% Ultrafine glass filler	Bisco, Inc., Schaumburg, IL, USA
Z250	UDMA, Bis-GMA, Bis-EMA, Zirconia/silica Particle size (0.01-3.5 l m), 82 (wt), 60 (vol)	3M ESPE Dental Products, St Paul, MN, US
Single Bond 2	10% silica filler size 5 nm	3M ESPE Dental Products, St Paul, MN, US
Silano	X-R-Si (OR)3n*	Angelus, Londria, PR, Brazil
Etch 32	32% phosphoric acid, benzo alkonium chloride	Bisco, Inc., Schaumburg, IL, USA
AH 26	Powder: bismuth oxide, methen-amine; Liquid: bisphenol epoxy resin	Dentsply, Konstanz, Germany

*X: Organofunctional group; R: Methylene group; OR: Hydrolizable group; Si: Silicon

Then, the root canal orifices of the roots were sealed with conventional glass ionomer (Ketac-Bond; 3M ESPE, Sumaré, SP, Brazil) and samples were stored at 37ºC and 100% relative humidity for 48 h [11].
For each sample, a 10-mm post space was prepared using Gates-Glidden drills. A tapered diamond bur (#850 023) (Diaswiss, Geneva, Switzerland) was used to enlarge the root canals to leave 1-mm-thick root canal dentin, measured with a digital caliper (Shoka Gulf, Spain) accurate to the nearest 0.01 mm [11,25]. To standardize the dentin wall thickness, reference points were marked on

Fig. 1. Reference points were marked on the cervical area with the use of a periodontal probe to standardize the thickness of dentinal wall

the cervical area with a periodontal probe (Fig. 1) [11].
After over flaring of the root canal, radiographic examinations were repeated from the buccolingual and mesiodistal directions to evaluate the uniform thickness of the remaining root canal dentin. Then, the root surfaces were dipped in molten wax (Cavex Set-up Regular Wax) so that a layer of wax, measuring 0.2-0.3 mm in thickness, covered the root surface up to 3 mm from the cut surface. The roots were then placed in polyvinyl chloride cylinders (measuring 25 mm in height and 21 mm in diameter), containing freshly mixed polystyrene resin. After polymerization of resin, the samples were retrieved from the cylinders, and root surface wax was eliminated with hot water. Polysiloxane impression material (Speedex, Coltene, Switzerland) was injected into the cylinders using a syringe, and the samples were placed in the cylinders again. Therefore, the periodontal ligament was simulated with a thickness of 0.2-0.3 mm using the above-mentioned technique. Then, the samples were randomly assigned to four groups (n=17) as follows:
Group 1: Two prefabricated glass fiber posts (Exacto, Angelus, Brazil) consisting of a master fiber measuring 1.8 mm in diameter and an accessory fiber measuring 1.25 mm in diameter were selected. The glass fiber posts were cleaned with ethanol, dried with water- and oil-free air, and silanized (Silano, Angelus, Brazil) for 1 min (according to the manufacturer's instructions). They were then cemented into

the root canal simultaneously. A dual-cure resin cement (DUO-LINK Universal; Bisco Inc., Schaumburg, IL, USA) was used as the luting cement and light-cured with a light intensity of 500 mW/cm^2 for 60 s using a LED curing unit (Demi; Kerr, CA, USA). The posts' coronally extended part was sectioned by a diamond disc (927 104; Diaswiss, Geneva, Switzerland) 2 mm above the flattened root surface. Then, the core was fabricated by composite resin (Z250; 3M ESPE, St. Paul, MN, USA) using a standardized custom-made ethylene-vinyl acetate mold with a uniform height of 6 mm and a ledge at 2 mm from the incisal margin at the palatal surface [23] (Fig. 2).

Fig. 2. Group 1: prefabricated glass fiber posts

Group 2: In this group, a braided glass fiber (Interlig, Angelus, Brazil) was adapted to the buccolingual wall of the root canal, and prefabricated glass fiber post, measuring 1.8 mm in diameter, was placed at the center of the root canal. The U-shaped braided glass fiber was pre-impregnated; it was adapted to the root canal walls after the root canal walls were impregnated with DUO-LINK resin cement with an endodontic plugger. The prefabricated glass fiber post was also placed at the center of the root canal using resin cement. The whole complex was light-cured similar to that in group 1 [11,23]. The fabrication of 2-mm coronal extension of the posts and cores was similar to that in group 1 (Fig. 3).

Group 3: In this group, two U-shaped braided glass fibers were adapted to the buccolingual and mesiodistal walls; after adaptation with the root canal walls and polymerization of the

Fig. 3. Group 2: prefabricated and custom-made braided glass fiber posts

complex of resin cement and glass fiber, the 2-mm coronal extension was maintained, similar to groups 1 and 2. Finally, the core was fabricated similar to that in groups 1 and 2 (Fig. 4).

Fig. 4. Group 3 custom-made braided glass fiber posts

Group 4: In this group, no posts were placed in the root canal. To fabricate the core, 2 mm of the gutta-percha was removed from the coronal part of the root canal, and the core was fabricated similar to that in previous groups.

All the samples were stored in an environment with 100% relative humidity for 24 h. Then, the samples underwent 1500 thermal cycles between 5-60ºC temperature and two 20-second intervals. Finally, the samples were transferred to a universal testing machine (Hounsfield Test Equipment, H5K-S Model; Surrey, England), and compressive static load was applied from the palatal aspect of the core at a crosshead speed of 0.5 mm/min, and 135º angle relative to the longitudinal axis of the tooth until fracture occurred (Fig. 5).

Fig. 5. Application of force at 135º angle relative to the tooth longitudinal axis in a universal testing machine

The fracture strength data were analyzed using one-way ANOVA and post hoc Tukey's test at a significance level of $P<0.05$. The Shapiro-Wilk test was used to evaluate the normal distribution of data.

RESULTS

Table 2 presents the mean and standard deviation of the fracture strength values of the study groups. The results of the Shapiro-Wilk test indicated the normal distribution of data. According to Table 2, the fracture strength values in groups 3 and 4 were maximum and minimum, respectively. One-way ANOVA showed a significant difference in the mean fracture strength values of the study groups ($P<0.001$).

Based on the results of pairwise comparisons of the study groups with post-hoc Tukey's test, there were no significant differences in the mean fracture strength values between groups 1, 2, and 3 ($P>0.05$). On the other hand, there were significant differences in the mean fracture strength values between these three groups and group 4 ($P<0.001$).

DISCUSSION

The present study evaluated the effect of a multi-post approach using prefabricated and custom-made glass fiber posts on the fracture resistance of crownless, over flared endodontically treated bovine central incisors. The results showed significant differences in the fracture resistance of study groups with glass fiber posts compared with the control group. An endodontically treated tooth might be similar to an empty cylinder [26] in that its flexural strength and fracture resistance are proportional to the fourth power of the difference of external and internal diameters (i.e., the thickness of the remaining dentinal wall of the root) [26,27]. Under the over flaring condition or over-widening of the root canals, in addition to the unfavorable stress absorption by the weakened dentinal wall of the root [28], there is a high volume of the luting cement used to fill the space between the post and the root canal wall. The low strength of the luting agent due to its inherent characteristics, trapping of air bubbles in the large volume of the luting agent [29], and its polymerization shrinkage, especially when the root C-factor is >200 [30], further compromise the fracture resistance and the biomechanical longevity of the tooth.

This problem is more prominent in anterior teeth due to the inflicted forces' oblique direction, and the resulting tensile/ compressive, and shearing stresses [10,31].

The multi-post technique in endodontically treated teeth with over flared root canals decreases the volume of the resin cement, and as a result, its polymerization shrinkage increases the post surface area and the interface between the post and core [32]. It also decreases the risk of post pull-out due to

Table 2. Mean and standard deviation of fracture strength values (N) in the study groups (n=17)

	Study group	Fracture load	Standard deviation	Minimum	Maximum	P-value
1	Two prefabricated glass fiber posts	947.01	133.35	765.00	1262.80	<0.001
2	Prefabricated glass fiber post + custom-made braided fiber post	912.40	160.11	710.20	1279.30	
3	Custom-made braided fiber	981.74	182.90	554.30	1229.00	
4	No post	461.46	185.04	181.50	1009.80	

an increase in retention and post adaptation with no need for further drilling of the root dentin [32]. Therefore, it increases the fracture resistance of the weakened roots [8,9,13] by significantly decreasing the stress [32], improving the stress distribution pattern [23], and increasing the durability of restoration in fatigue-cyclic loading and thermic conditions [32]. However, Clavijo et al, [11] Martelli et al, [17] and Zogheib et al. [18] did not report such a result.

Irrespective of the type of glass fiber post technique used, its elastic modulus, which is comparable to that of the composite resin and dentin causes the polymerized fiber post-resin cement complex to form a mono-block structure in the root. This complex increases the fracture resistance of endodontically treated tooth to the level of an intact tooth [27-32], by more even distribution of stresses and decreasing stress concentration [3].

According to pairwise comparisons between glass fiber post groups, although the difference was not significant, group 3 exhibited the maximum fracture strength between the study groups.

The Interlig braided glass fiber is pre-impregnated [33]; when it is adapted to the root dentin, it is polymerized along with the resin luting agent. Therefore, the cement-dentin interface is subjected to less stress. On the other hand, its tensile strength, density, and high elongation percentage allow it to tolerate the inflicted stresses without fracture [33]. The braided structure of the fiber post results in the modification of the forces inflicted on its braided structure before being transferred to the resin cement and tooth [34]. On the other hand, its geometry allows its better adaptation and integration with the root canal wall [35]. Besides, by enhancing the inherent plastic deformation of the weakened dentinal walls [36] and establishing a strong bond with the dentinal walls of the root [16,37], it makes it possible for the tooth-post complex to resist stresses as a single unit.

After group 3, group 1 exhibited a high fracture strength. In prefabricated glass fiber posts, the glass fiber content is at the maximum possible level (65%), which might affect the mechanical properties of the post, including an increase in stiffness, which increases the fracture resistance of the tooth [38]. In addition to this favorable property, smaller cement thickness, improved adaptation, and optimal pull-out bond strength should also be considered as other advantages of this type of post. From the statics science point of view, restorations with several reinforcing posts have high bearing capacity against extrusive/intrusive and bending forces [32]. In other words, fibers placed in the same direction and away from the longitudinal axis of the tooth provide a condition for creation, transfer, and distribution of stress, similar to that in a natural tooth, minimizing the risk of root fracture, especially in the apical area [32].

According to the results of Mortazavi et al, [13] who evaluated the role of braided fiber posts, as an accessory post, in reinforcement of endodontically treated teeth [13], it was expected that when the prefabricated cone-shaped and custom-made braided glass fiber posts were used for reconstruction of teeth, the specific properties of each fiber post would yield the highest fracture resistance. Although the difference in the mean numerical values of the fracture resistance between this group and the control group was significant, group 2 exhibited low fracture strength compared with groups 3 and 1. It appears that the use of similar glass fiber posts would have a higher reinforcing effect on fracture resistance of crownless over flared endodontically treated anterior teeth. Finally, it should be pointed out that the present study was carried out in vitro and under static forces despite the attempt to simulate the periodontal ligament. Since fatigue of the restored complex is the main etiologic factor for fractures under clinical conditions [39], future studies should be designed by considering an aging period under dynamic loading.

CONCLUSSION

Under the limitations of the present study, it can be concluded that:

1. The multi-post approach, using prefabricated and custom-made glass fiber posts, increased

the fracture resistance of crownless over flared endodontically treated bovine incisors.
2. Similar glass fiber posts, prefabricated or custom-made, can result in higher fracture resistance.

CONFLICT OF INTEREST STATEMENT

None declared.

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