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Fracture resistances of zirconia, cast Ni-Cr, and fiber-glass composite posts under all-ceramic crowns in endodontically treated premolars

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PURPOSE. The aim of the present study was to evaluate the fracture resistances of zirconia, cast nickel-chromium alloy (Ni-Cr), and fiber-composite post systems under all-ceramic crowns in endodontically treated mandibular first premolars. **MATERIALS AND METHODS.** A total of 36 extracted human mandibular premolars were selected, subjected to standard endodontic treatment, and divided into three groups (n=12) as follows: cast Ni-Cr post-and-core, one-piece custom-milled zirconia post-and-core, and prefabricated fiber-glass post with composite resin core. Each specimen had an all-ceramic crown with zirconia coping and was then loaded to failure using a universal testing machine at a cross-head speed of 0.5 mm/min, at an angle of 45 degrees to the long axis of the roots. Fracture resistance and modes of failure were analyzed. The significance of the results was assessed using analysis of variance (ANOVA) and Tukey honest significance difference (HSD) tests (α=.05). **RESULTS.** Fiber-glass posts with composite cores showed the highest fracture resistance values (915.70±323 N), and the zirconia post system showed the lowest resistance (435.34±220 N). The corresponding mean value for the Ni-Cr casting post and cores was reported as 780.59±270 N. The differences among the groups were statistically significant (P<.05) for the zirconia group, as tested by ANOVA and Tukey HSD tests. **CONCLUSION.** The fracture resistance of zirconia post-and-core systems was found to be significantly lower than those of fiber-glass and cast Ni-Cr post systems. Moreover, catastrophic and non-restorable fractures were more prevalent in teeth restored by zirconia posts. ***[J Adv Prosthodont 2017;9:170-5]***

KEYWORDS: Fracture; Endodontically treated teeth; Post and core; Zirconia

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INTRODUCTION

A tooth undergoing root canal treatment shows little resistance to occlusal forces due to the significant loss of their coronal structure. In order to increase the longevity of the final restoration, use of a post-and-core system is often indicated.[1] Proper post selection and load distribution along the roots greatly reduces the risk of root fracture.[2] Moreover, the amount of intact tooth structure, as well as the characteristics of the post, including its material, elastic modulus, diameter, and height, contribute to resistance to the fracture of teeth restored by post and cores.[3]

High success rate, favorable long-term prognosis, easy

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manipulation, and low cost are responsible for the popularity of cast metal post-and-core systems. Furthermore, in these systems, posts are integrated and custom-made and reproduce the morphology of the canal with good accuracy.[4] In fact, in most clinical situations, cast metal post-and-core systems are still are among the best treatment options for restoring endodontically treated teeth.[5] However, reports of low biocompatibility and chances of corrosion and root fracture, along with the negative effects they have on the esthetics of the teeth have prompted clinicians look for alternative techniques for the restoration of endodontically treated teeth.[6-9] A progress in the field of tooth-colored materials has directed attention towards the use of composite and ceramics.[7] The major problem in restoring anterior pulpless teeth is the dark shadow appearance of metal or carbon fiber under the ceramic crowns.[10] Therefore, tooth-colored post-and-core systems such as zirconia-covered carbon fiber, zirconia and fiber reinforced posts, were introduced to improve the esthetics of endodontically treated teeth.[11]

Castable glass ceramics and glass infiltrated ceramics were first used for this purpose.[12] In 1995, Meyenberg introduced zirconia posts.[9] Nowadays, zirconia is widely used in dentistry, due to its chemical stability, high mechanical strength, a Young's Modulus similar to stainless-steel alloys, and above all, the similarity of its color to that of teeth.[13] Streacker and Awad developed the process of milling one-piece zirconia post and core out of yttrium tetragonal zirconium polycrystals using CAD-CAM machines.[14,15] In this technique, milling is performed based on the data of the post pattern, which are transferred through a scanner to a computer. A case report has shown this technique to give rise to an esthetic, yet stiff post-and-core system, along with its maximum canal fitness; however, the author indicated that a significant difference exists between the marginal gap of the produced post-and-core and its acrylic pattern.[13]

On the one hand, application of these systems has always been a matter of debate, as the high elastic modulus of zirconia is responsible for catastrophic fractures of roots in teeth restored with these systems.[16] On the other hand, there are some articles suggesting that zirconia could even reinforce the tooth structure due to its mechanical characteristics and offer better stress distribution along the roots.[17] Akkayan and Gülmez[18] showed fiber-glass and zirconia posts to have the same fracture resistance. In a study by Heydecke investigating the fracture strength of endodontically treated teeth with different post-and-core systems, no significant differences were detected in the use of titanium, zirconia or ceramic posts with either ceramic or composite cores.[19] Fracture resistance and mode of failure were also the same for prefabricated zirconia, fiber and casting posts in the study of Xible *et al.*.[20]

Fiber-glass posts are considered to cause fewer root fractures. Gu stated that fiber and titanium posts perform better when accompanied by resin cements[21]; while according to Torres-Sanchez, use of reinforced glass ionomer cements along with fiber posts can greatly improve the fracture strength of endodontically treated teeth.[22] However, controversies still remain regarding the comparison of these systems with traditional casting ones.

The aim of the present study was to evaluate the fracture resistances of zirconia, cast nickel-chromium alloy (Ni-Cr), and fiber-composite post systems under all-ceramic crowns in endodontically treated mandibular first premolars.

MATERIALS AND METHODS

Based on the data of the previous studies, with the help of Minitab software and a one-way analysis of variance (ANOVA) test, considering $\alpha = 0.05$ and $\beta = 0.2$, with a minimal difference of 160 N and pooled standard deviation of 140 N, the number of specimens required in each test group was determined to be 12. Thus, a total of 36 extracted mandibular first premolars extracted mostly for orthodontic reasons, with almost intact crowns, free of previous endodontic treatment, restorations, cracks, fractures, and significant erosion or enamel hypoplastic deficiencies, were selected. The patients had given their informed consents before extraction of their teeth for research purposes.

Samples were randomly divided into three groups (n = 12) and stored in 0.5% chloramine-T solution (Merck-Schuchardt, OHG, Germany) for a period of 2 days before the beginning of the study.[13] Any calculus or residual debris from the teeth surface was removed, and the samples were cleaned using pumice and a slow-speed handpiece (NSK, Nakanishi, Japan). After caries and unsupported enamels were removed, the anatomic crowns of the teeth were sectioned parallel to the cementoenamel junction (CEJ) using a diamond rotary cutting instrument (DNZ, Germany) on a high-speed handpiece (NSK, Nakanishi, Japan) under water keeping at least 2 mm of sound structure above the CEJ to provide the ferrule. The teeth were stored in 0.9% normal saline for the rest of the study.

Standard root canal treatments were carried out on all teeth. The working length was set at 0.5 mm to the radiographic apex. Cleaning and shaping of the canals was performed using 5.25% sodium hypochlorite, standard files (K-file, Mani, Japan), and size-2 drills (Gates Glidden, Mani, Japan) through the step-back technique (master apical file = 40). The canals were then obturated with a lateral condensation technique using gutta percha (Meta biomed, South Korea) and eugenol-free sealer (AH26, Dentsply, De Trey, Konstanz, Germany).

In order to prepare the teeth to receive all-ceramic crowns, a 1-mm wide radial shoulder finishing line was prepared at 0.5 mm above the CEJ. Leaving 4 mm of gutta percha for the apical seal, the dowel space was prepared with the use of an appropriate size of peeso reamer (Mani, Utsunomiya, Japan). For the teeth in the first two groups, one-piece patterns of post and cores were made directly with self-cure acrylic resin (GC Corporation, Tokyo, Japan) (Fig. 1).

In the first group, the patterns were casted in Ni-Cr alloy (Wiron 99, Bego, Bremen, Germany). In the second group,

Fig. 1. Prepared acrylic patterns of post-cores in the first two groups.

Fig. 2. A sample and an all ceramic crown with zirconia coping.

integrated zirconia post and cores were prepared using a MAD-MAM machine (Zirkonzahn, Gais, Italy). After making the required adjustments and ensuring suitability using radiography, all posts were cemented into their corresponding teeth using Panavia resin cement (Panavia F2.0, Kuraray, Noritake, Dental Inc., Tokyo, Japan) according to the manufacturer's instructions. For the teeth in the third group, fiber-glass posts (Light post, Illusion X-RO, RTD, Saint egreve, France) and composite cores (PhotoCore, Kuraray Noritake, Tokyo, Japan) were used.

The appropriate size of fiber-glass post was selected, as confirmed by radiography, and cemented as described above (Panavia F2.0, Kuraray, Noritake, Dental Inc., Tokyo, Japan). The composite core was then formed. All samples were next scanned to receive all-ceramic crowns with zirconia coping using the CAD-CAM technique (Cerec 4.0, Sirona Dental Systems, Bensheim, Germany). Prepared crowns were cemented with Panavia cement, using the same protocol described above (Fig. 2).

In order to receive the loads, samples were embedded, with the help of a surveyor, parallel to their vertical axis in acrylic blocks (Acropars, Tehran, Iran) 2 mm above the CEJ.[23-25] Loads were then applied using a universal testing machine (Zwick Roell Group, Ulm, Germany) at a crosshead speed of 0.5 mm/min on the central fossa of each crown, through a 4-mm diameter spherical wedge, at an angle of 45 degrees to the long axis of the roots (Fig. 3). The first drop in the stress graph was considered to be the fracture point, and loading was stopped thereafter. Finally, the modes of fracture were inspected.

SPSS was used for statistical analysis. Mean fracture resistance and the frequency of fracture modes within the study groups were calculated. ANOVA and Tukey honest significance difference (HSD) tests served for comparison of fracture resistance among the study groups. Significance level was set at 0.05.

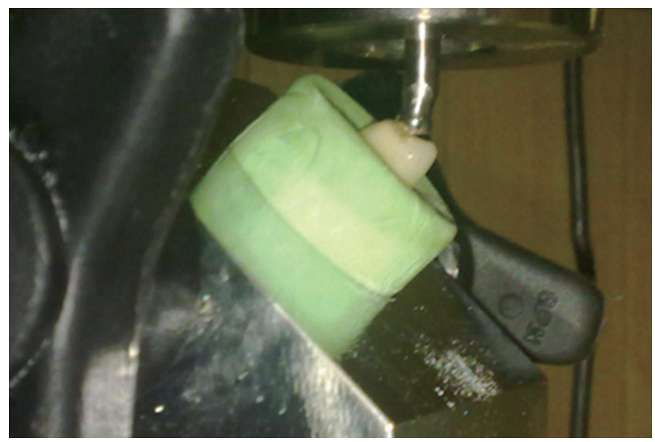

Fig. 3. Loading of a sample in universal testing machine to the point of fracture.

RESULTS

In the present study, fiber-glass posts with composite cores showed the highest fracture resistance values (915.70 ± 323 N) and the zirconia post system showed the lowest resistance (435.34 ± 220 N). The corresponding mean value for the Ni-Cr casting post and cores was reported as 780.59 ± 270 N (Table 1). These differences among the groups were statistically significant ($P < .05$) for the zirconia group, as tested by ANOVA and Tukey HSD tests. Although higher values of fracture resistance were recorded in the fiber-glass group compared with the cast metal post-and-core system, this difference was not statistically significant ($P > .05$). Error bars of mean fracture resistance, and 95% confidence intervals in the study groups are shown in Fig. 4.

In the cast metal group, the majority of fractures occurred in the veneering porcelain, with one case undergoing fracture in the cervical area of the root (at the CEJ) and another with a horizontal root facture (Fig. 5). In the zirconia post-and-core group, the root fracture was observed in 10 samples (83.3%), of which the apical 2 mm of the post

Table 1. Mean, standard deviation, and standard error of fracture resistance in the three groups of extracted mandibular premolars undergoing three different post & core treatments

Post type	N	Mean	Std. Deviation	Std. Error
Casting	12	780.5917	270.53232	78.09595
Fiber	12	915.7083	323.59966	93.41517
Zirconia	12	435.3417	220.41138	63.62729

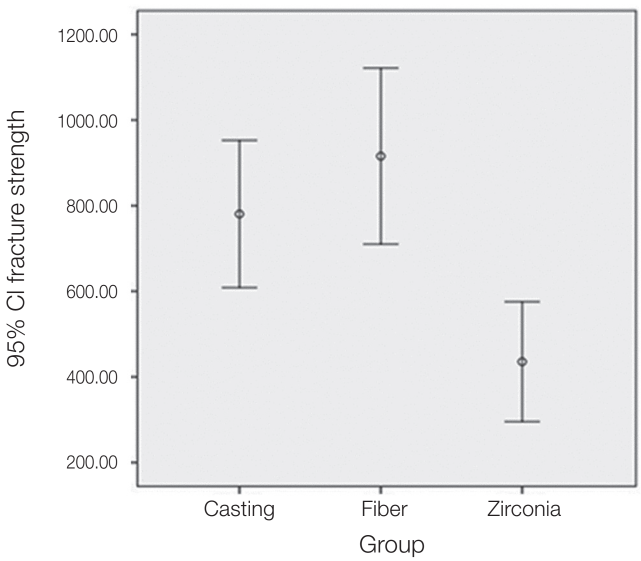

Fig. 4. Error bar and condinfence interval of 95%.

Fig. 5. Porcelain fracture in cast Ni-Cr post-core system.

was broken in two, and porcelain was fractured in the other two (16.7%). Among the samples with a fiber-glass post and composite core, detachment of the crown at the CEJ was the prevailing fracture mode (91.7%), with just one case of root fracture (8.3%).

DISCUSSION

The present study investigated the fracture resistance of zirconia, cast Ni-Cr, and fiber-glass composite post systems in endodontically treated mandibular first premolars with all-ceramic crowns. According to the results, custom-made, one-piece zirconia post-cores showed the significantly lowest mean values for fracture resistance, and the values were higher in fiber-glass posts; however, this difference was not significant in comparison with the cast metal group.

The higher fracture resistance of fiber-glass posts can be attributed to the similarity of its elastic modulus to that of dentine, as well as its ability to bond to the tooth.[18,21] Forces to a tooth that has been restored using a fiber-glass post are predominantly absorbed by the post itself, thus reducing stress on the root and leading to a lower probability of fracture.[16,26,27] Several studies have supported this hypothesis.[21,26] Gu *et al.*[21] reported higher fracture resistance for fiber-glass posts restoring anterior teeth, especially when used with resin cements, compared with cast Ni-Cr posts. Similar results were achieved in a previous study in which the fracture resistance of fiber glass was compared with cast gold posts for restoring endodontically treated premolars.[22] In another study comparing fracture resistance of stainless-steel and fiber-glass posts in teeth restored with all-ceramic crowns, Li *et al.*[28] reported higher fracture resistance for fiber-glass posts.

One of the reasons for the lower fracture resistance of custom-milled zirconia post-cores could be the mechanical properties of zirconia. The yield strength of posts made from zirconia has been reported to be higher than that of fiber-glass and titanium posts (58 ± 4 vs. 27 ± 1 and 54 ± 3, respectively),[27,29] and their flexural strength is similar to that of gold and titanium (900-1200 MPa).[30,31] On the other hand, the high elastic modulus of these posts (200 MPa) makes them very strong and stiff, and prevents them from showing a plastic behavior.[29,32] When a post-and-core system with a high elastic modulus is loaded, a slowly growing microcrack develops at the post cement-dentine interface and, as the post loses its integrity with the dentine, it acts in the manner of a wedge transferring stress to the dentine and causing root fracture.[26,33]

The fracture resistance of fiber-glass posts was not significantly different to that of custom-milled zirconia posts in a study by Beck *et al.*.[34] However, that study was performed on opaque plastic-made canals simulating the root canal system, in which the samples underwent 50-N cyclic loading. Furthermore, although the crown was not placed on the samples, it has been shown that crown coverage leads to an even greater distribution of forces and makes it more similar to the clinical situation. In fact, crown placement significantly increases the fracture strength of teeth in these kinds of studies.[34] Cormier *et al.*,[35] investigating the fracture strength of zirconia posts, observed that fracture resistances in loading the post alone, in loading the post-and-core system without the crown, and in loading while complete coverage is placed upon the system were 105.1, 179.1, and 238.8 N, respectively. Friedel and Kern[12] compared the fracture resistance of various systems of zirconia posts with and without crowns and concluded that when a crown is placed over the tooth, the post-and-core system does not play an important role in fracture resistance, as it helps balance the forces on the tooth-restoration complex.

Regarding the mode of fracture, in the cast metal group the majority of fractures occurred as micro-cracks in the porcelain of the crown at the CEJ. The most prevalent modes of fracture were root fracture at the apical area in the zirconia post-and-core group and fracture at the CEJ leading to detachment of the crown in the fiber-glass post group.

Fractures in teeth restored by post-core crown systems are sometimes restorable via crown displacement, crown lengthening, forced eruption, or re-build ups. On the contrary, non-restorable deep-root fractures are considered as catastrophic fractures leaving no choice other than tooth extraction.[36] It should be taken into account that stress distribution along the root is significantly dependent on the characteristics of the post material. As noted previously, the elastic modulus of fiber-glass posts is between 30-40 GPa, which is more similar to that of dentin than either cast metal or zirconia. Consequently, using these posts to restore endodontically treated teeth facilitates the natural bending movements of the tooth, leading to less stress accumulation in the interfaces, and as a result, the tooth-restoration complex shows a biomechanical behavior similar to that of the intact tooth. Moreover, it is possible to remove these posts with a lower risk of perforation.[37] From this point of view, in our study, the fractures in the zirconia post group were mostly non-restorable, while the fiber-glass post group showed more reparable fractures.[36] This finding is consistent with various previous studies. Gu *et al.*[21] also reported that most of the fractures in teeth restored by fiber-glass posts are restorable, contrary to those in teeth restored by zirconia and Ni-Cr. Freedman[38] stated that due to greater stress accumulation in the apical area, cast Ni-Cr post-and-core systems caused more vertical root fractures compared with other systems. Akkayan and Gülmez[18] also observed that catastrophic fractures are more prevalent among titanium and zirconia posts compared with quartz fiber and fiber-glass posts. They hypothesized that the rigidity and high elastic moduli of titanium and zirconia caused direct transfer of forces to the tooth without any decrease or absorption by the post-and-core system and were considered to be the main cause of these fractures.

In order to maintain sufficient resistance in zirconia custom-made posts, despite the adjustments needed to seat it, the post-core system requires sufficient bulk. This extra preparation of the canal can sometimes be problematic, especially in delicate and curved roots.[38] We first tried to use the CAD-CAM system for milling of the zirconia patterns. However, due to technical problems, it was almost impossible to prepare the narrow parts of the acrylic patterns, especially in their 2-mm apical region using this system, and the final posts were made shorter than their acrylic counterparts. Thus, in order to preserve the tooth structure, we tried to avoid excessive canal preparation and use the MAD-MAM system for sample preparation. One of the weaknesses of this system, however, is its technical sensitivity, leading to decreased accuracy of the posts. Therefore, we recommend using a CAD-CAM system that is able to prepare the apical 2 mm of the zirconia post in future studies.

With regard to the demand for esthetic treatments and the increasing use of ceramic restorations, it is necessary to consider the fracture resistance of restorations in anterior teeth. It should be noted that, because of the unavailability of sufficient anterior teeth, we had to use premolars instead in our study. Although the maximum bite force on the anterior teeth is less than that of the premolars (323-485 vs. 424-583 N), the existence of horizontal forces and shear stress on these teeth challenges the applicability of our findings. Considering this fact, we suggest a similar study on a sufficient number of anterior teeth in the future. In our study, a universal testing machine was used to measure fracture resistance in a static manner. However, we suggest that the use of a chewing simulator and cyclic loading of the samples would provide more consistent results to the clinical situation.

CONCLUSION

Within the limitations of this study, fracture resistance of zirconia post-and-core systems was found to be significantly lower than those of fiber-glass and cast Ni-Cr post systems. Moreover, catastrophic and non-restorable fractures in teeth restored by zirconia posts were more prevalent. Therefore, until further clinical studies with long-term follow-ups on zirconia posts are available, the use of cast Ni-Cr post systems and tooth-colored systems with a similar elastic modulus to the dentin might provide more acceptable results.

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