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ORIGINAL ARTICLE

The effect of post length and core material on root fracture with respect to different post materials

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Abstract

Objective. The aim of this study was to evaluate the effect of different core materials and post length on the fracture strength of different posts (CAD/CAM zirconia post (ZR post)) and an individually formed glass fiber reinforced composite post (FRC post). ***Materials and methods.*** One hundred maxillary central incisors received endodontic treatment and were divided into two groups according to the post length: (1) 10 mm in length and (2) 15 mm in length ($n = 50$/per group). Then the specimens were randomly assigned into five sub-groups ($n = 10$/per group) as follows: One-piece milled zirconia post and core (group Zr), zirconia post with resin core (Biscore, Bisco) (group Zr/R), zirconia post with resin composite core (Admira, Voco) (group Zr/RC), FRC post with resin core (group F/R) and FRC post with resin composite core (group F/RC). The posts were cemented with a self-adhesive luting agent according to the manufacturer's instructions by using endo tips and light-cured for 40 s using a halogen light curing unit. Metal crowns were made for each specimen, cemented and loaded to failure. Fracture loads (N) and modes of failure were recorded. The data were analyzed using three-way analysis of variance (ANOVA) followed by Tukey's post-hoc test ($p < 0.001$). ***Results.*** Fracture strength of roots was significantly affected by the type of post material ($p < 0.05$) and post length ($p < 0.05$), but not by the type of core materials used ($p = 0.078$). ***Conclusion.*** Longer zirconia posts with zirconia- or resin-based cores can be recommended as an alternative to FRC posts with resin-based cores. The fracture patterns observed in teeth restored with fiber posts were more favorable than teeth restored with zirconia posts. ***Clinical significance.*** A higher restoring success rate can be achieved by fiber posts rather than zirconia posts, since the failure mode for these posts would be restorable. Additionally, post length is a more critical factor in teeth restored with one-piece milled zirconia posts than in those restored with fiber posts.

Key Words: *FRC post, fracture strength, post length, resin core, zirconia post*

Introduction

The restoration of the severely damaged endodontically-treated anterior teeth is considered a serious challenge in contemporary dental practice due to the inherent demand for excellent esthetics. In this respect, research has focused on esthetic post and core materials [1–4]. Various tooth-colored posts made of either fiber-reinforced resin composites (FRC) or yttrium stabilized zirconia (Y-TZP)-based ceramics are preferred as alternatives to metal posts for restoring endodontically-treated teeth [5,6]. Zirconia posts exhibit corrosion strength, biocompatibility, appropriate optical properties, high strength to bending forces, high flexural strength (900−1200 MPa) and fracture toughness [7,8]. The flexural strengths of these posts were comparable to cast gold or titanium [9]. Besides, the high elastic modulus of zirconia posts at 200 MPa causes stress to be transferred to the less rigid dentin, thereby resulting in root fractures [10,11]. On the other hand, the major advantage of FRC posts is a similar modulus of elasticity to dentin which allows reducing the risk of vertical root fractures. Furthermore, FRC posts offer a better biomechanical performance and thereby affect the strength and resistance of the tooth [7,12].

Recently, tooth-colored resin core materials are used as core build-up materials since they can prevent root fractures of non-vital teeth and require minimal intervention and cavity preparation [13]. The use of pre-fabricated posts in combination with resin composites to directly build-up the core as an alternative to cast posts and cores is expected to yield a more natural and esthetic appearance of the final restoration [1]. In addition, as an alternative to resin composite

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cores bonded to zirconia posts, high-strength ceramics are used with copy-milling systems for the fabrication of cores [3,14]. In view of the great variety of the core systems, the question is the type of core that performs best in directly building up a core on a posted tooth has not yet been systematically addressed.

Previous studies have reported that the fracture strength of post and core restorations depends on several factors including post material, post diameter, post length, post design and core material [15,16]. In particular, regarding the post length, previous studies reported that increasing the length of the post results in a more favorable stress distribution along the restored roots and improves the resistance of the tooth [17]. Therefore, the posts should be at least the same length as the crown height or two thirds of the root length [2,18]. However, increasing post length is usually accomplished with additional root wall enlargement, which could lead to weakening of the root [19].

Based on these considerations, the purpose of this investigation was to compare the fracture strength and failure pattern of the endodontically-treated teeth restored with various core materials used with either fiber or zirconia posts in different lengths. The tested null hypothesis was 3-fold. (1) There would be no difference between fracture strength of zirconia posts and FRC posts. (2) The length of post in root canal does not significantly affect the fracture strength of endodontically-treated teeth. (3) The type of core material has no contributory effect on fracture strength.

Materials and methods

Tooth selection

Freshly extracted human maxillary central incisors with similar size and straight roots were reduced to a standardized root length of 16 mm. All specimens were examined under a stereomicroscope to ensure the absence of cracks. The mesiodistal and buccolingual diameters of the coronal planes were measured with a digital caliper and roots presenting a difference of 20% from the mean were discarded [20], leaving a total of 100 maxillary central incisor roots.

Specimen preparation

Canal length was determined using a #10 K-file and the working length was determined by subtracting 1 mm from the canal length. The roots were prepared with the ProFile rotary files (Dentsply Tulsa Dental, Tulsa, OK) up to size 40/0.06 in conjunction with RC-Prep lubrication (Premier Dental Products, Tulsa, OK) and 2 mL of 5.25% sodium hypochlorite (NaOCl) irrigation between each file size. The root canals received a final irrigation of 5 mL 17% ethylenediaminetetraacetic acid (EDTA) and 5 mL 2.5% NaOCl, after which the canals were flushed with 10 mL distilled water to avoid the prolonged effect of EDTA and NaOCl. The canals were subsequently dried with paper points. Then the canals were obturated with single 0.06 taper size 40 gutta-percha cones (Dentsply-Maillefer) in conjunction with AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany). After the completion of endodontic treatment, cervical root canal openings were filled with a provisional restorative material (Cavit-G; 3M ESPE AG, Seefeld, Germany) [21]. All teeth were stored at 37°C and 100% humidity for 48 h to allow for complete setting of the sealers.

Preparation of zirconia posts

CAD/CAM zirconia posts (1.5 mm in diameter and 10 mm/15 mm in length) were manufactured from pre-sintered Y-TZP disc shaped blocks (Copran Zr; WhitePeaks Dental GmbH & Co. KG, Essen, Germany). Posts were sintered to full density in a high-temperature furnace (Protherm; B&D Dental Origin Milling, UT, West Valley) at 1450°C for 2 h according to the manufacturer's instructions. All of the zirconia posts received an airborne-particle abrasion with 30-mm silicatized Al_2O_3 particles (CoJet_Sand; 3M Espe, Seefeld, Germany) at 280 kPa pressure from a distance of 10 mm for 20 s. Posts were rotated during this procedure using an electric motor (PSR 2.4V; Robert Bosch GmbH, Stuttgart, Germany) at 130 rpm to apply the airborne particles to the entire treatment surface homogenously. The specimens were then ultrasonically cleaned in 96% isopropyl alcohol for 3 min.

Post luting procedures

The roots were randomly assigned into two groups with respect to the post length: (1) 10 mm in length and (2) 15 mm in length (n = 50/per group). The gutta-percha was removed with a warm plugger (Sybron Dental Specialties; Romulus, MI) leaving a minimum 5 mm apical seal and creating a post space of 10 mm from the apical surface, in the groups with 15 mm posts. Additionally, a minimum 10 mm apical seal was left and a post space of 5 mm from the apical surface was created, in the groups with 10 mm posts. Twenty drills (Parapost drill, Coltène/Whaledent, Cuyahoga Falls, OH) having 1.5-mm diameter (one drill for five post space preparation) were used in the study. Thereafter, the roots were assigned into five experimental groups (n = 10/group) as follows: (1) One piece milled zirconia post and core (group Zr); (2) Zirconia post with resin core (Biscore, Bisco Inc, Schaumburg IL, USA) (group Zr/R); (3) Zirconia post with resin composite core (Admira, Voco GmbH, Cuxhaven, Germany) (group Zr/RC); (4)

FRC post (everStick, Sticknet Ltd, Turku, Finland) with resin core (group F/R); and (5) FRC post with resin composite core (group F/RC).

All the prepared root canals were finally flushed with 2 ml NaOCl solution (5.25%), after which it was dried with paper points (Dentsply-Maillefer). FRC posts were sectioned to the desired length by a sharp scissor according to the manufacturer's recommendations. ZR post surfaces were cleaned with alcohol, thoroughly rinsed with distilled water and air-dried.

All posts (1.5 mm in diameter) were luted with a self-adhesive luting agent (Clearfil SA Cement; Kuraray Medical Co, Osaka, Japan) according to the manufacturer's instructions. Following placement of the posts with slight pressure, in all groups, excess luting cement was removed. The luting agent was light cured with a LED light-curing unit (Elipar Freelight 2; 3M ESPE, St. Paul, MN) for 20 s in each of four directions (buccally, lingually, mesially and distally). The output of the light was checked with a radiometer on the curing unit itself to ensure accurate light intensity.

Standardized molds (DentinBuild Formkappe Size I; Gebr Brasseler GmbH) were used to create cores of equal sizes. Resin-based cores were built up to yield an abutment height of 6 mm measured from the buccal cemento–enamel junction. Following application of the resin-based core materials; the specimens were light-cured for 20 s in each of four directions (buccally, lingually and proximally). Then the patterns were prepared to the desired shape with a high-speed handpiece and appropriate diamond burs with a total abutment height of 5 mm core material and 6° taper were built. The specimens were prepared by 1.5 mm facial reduction with a chamfer finish line and 0.5 mm chamfered lingual reduction. Patterns based on a post with resin-based core materials were used and a core pattern was built up with autopolymerizing acrylic resin (Pattern Resin; GC Corp, Tokyo, Japan). This pattern served as a basis for the copy-milling process. The patterns were fixed in the copy-milling machine (White CAM 5.0; White-Peaks Dental GmbH & Co. KG) with sprues located at the apical and coronal portions and milled in presintered zirconia ceramic following the manufacturer's recommendations. Following sinterization, one-piece milled zirconia post-cores were cemented according to previously mentioned procedures.

For the standardization of applied force during the compressive test, metal crowns were made for all of the specimens. Impressions of the teeth were made with a vinyl polysiloxane material (Aquasil Ultra LV; Dentsply DeTrey GmbH, Konstanz, Germany) and metal crowns were fabricated using Ni-Cr alloy (Wiron 99; BEGO, Bremen, Germany). The crowns were designed with a small palatal rest 1 mm wide and 2 mm below the incisal edge. The crowns were cemented with resin cement (Clearfil SA). After the cementation procedures, the teeth were stored in distilled water for 7 days at 37°C. All specimens were prepared by the same operator.

Specimens were embedded in autopolymerizing acrylic resin (Palapress Vario, Heraeus Kulzer, Wehrheim, Germany) at 2 mm from the cemento–enamel junction to simulate the bone level. Root surfaces were covered with 0.2–0.3 mm thick foil. At the beginning of the polymerization period, the teeth were removed from the resin blocks along the long axis and the spacers were removed from the root surfaces. A polyether impression material (Impregum^{TM} Soft; 3 M/ESPE, Seefeld, Germany), using a moulding syringe, was injected into the acrylic resin blocks and the teeth were reinserted into resin cylinders. A standardized silicone layer that simulated a periodontal ligament was thus created. Figure 1 shows the schematic illustration of sample preparation and fracture strength test. A compressive load was applied on the lingual surface (2 mm below the incisal edge) at a 45° angle and crosshead speed of 0.5 mm/min until a fracture occurred (Figure 1).

Failure modes were observed with an optical microscope at a ×40 magnification (Stereomicroscope; Wild M3B, Heerbrugg, Switzerland). Two specimens typical of the failure modes from each group were prepared for scanning electron microscope (SEM) analysis [7]. The specimens were sputter-coated (Bal-Tec SCD 050 Sputter Coater; Bal-Tec, Liechtenstein) with gold and observed with a SEM (JSM-5500; JEOL, Tokyo, Japan).

Statistical analysis

Three-factor analysis of variance (ANOVA) (SPSS, Chicago, IL) was used to test the effects of post materials, post lengths and core material ($p < 0.05$). One-way analysis of variance and Tukey's post-hoc tests were performed to determine the differences in fracture strength results among the groups including assessment of possible interaction, which was used at a significance level of $p < 0.05$. Moreover, statistical differences in failure modes were investigated by chi-square tests at a significance level of $p < 0.05$.

Results

The mean fracture strength values, standard deviations and the differences within the groups are presented in Figure 2. Three-way ANOVA revealed that the type of post material had a significant effect on fracture strength values ($p < 0.001$). However, fracture strength values were not significantly affected by post length and core material ($p = 0.007$ and $p = 0.078$, respectively). There were no significant two-factor interactions between the post length and the post material ($p = 0.015$), as well as between the post and core materials ($p = 0.928$). However, the

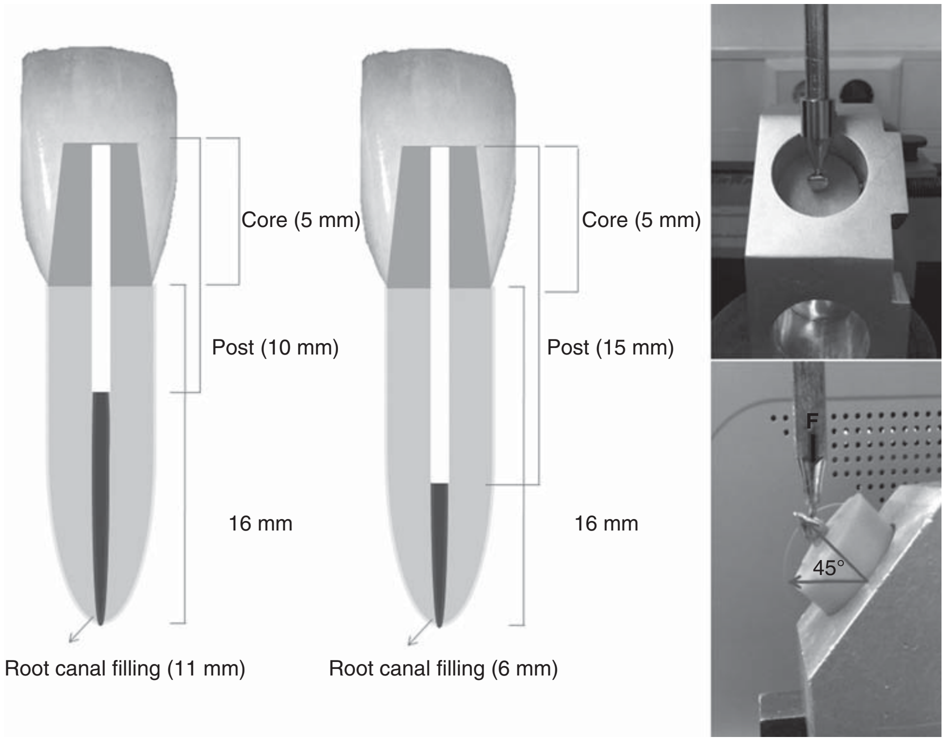


Figure 1. Dimensions of posts/cores and illustration of specimen preparation. Apparatus for compressive testing with specimen mounted in a universal testing machine at an angle of 135° in relation to the long axis of posts.

interaction between post length and core material was significant ($p < 0.001$). Furthermore, no significant interactions were observed between post material, post length and core material ($p = 0.454$). Detailed analyses of these interactions are presented in Table I.

Statistical analysis demonstrated that zirconia posts (163.01 ± 5.28 N) had significantly higher fracture strength values than FRC posts (93.48 ± 7.38 N) ($p < 0.05$). Moreover, the fracture strength values of the group Zr with a post length of 15 mm (191.41 ± 61.79 N) was statistically higher than that of the group Zr with a post length of 10 mm (108.06 ± 31.09 N) ($p < 0.05$). However, there were no statistically significant differences between 10 mm and 15 mm posts of the groups Zr/R, group Zr/RC, group F/R and the group F/RC. In addition, no significant differences

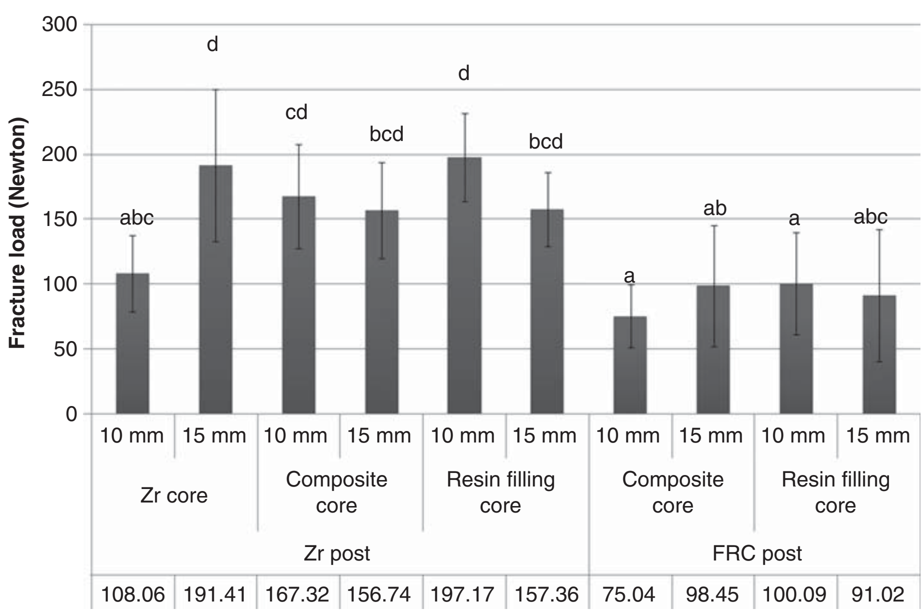


Figure 2. Fracture strength values in each group. * Means with same letter are not significantly different ($p > 0.05$).

Table I. Three-way analysis of variance for fracture strength results.

Source of variation	Type III sum of squares	df	Mean square	*F*	Sig.
Corrected model	158,354.049*a*	9	17,594.894	10.732	0.000
Intercept	1,348,481.554	1	1,348,481.554	822.524	0.000
Post type	99,627.465	1	99,627.465	60.769	0.000
Core material	8,633.052	2	4,316.526	2.633	0.078
Post length	12,490.391	1	12,490.391	7.619	0.007
Post type * Core material	13.597	1	13.597	0.008	0.928
Post type * Post length	10,171.373	1	10,171.373	6.204	0.015
Core material * Post length	38,786.736	2	19,393.368	11.829	0.000
Post type * Core material * Post length	926.486	1	926.486	0.565	0.454
Error	131,155.445	80	1,639.443		
Total	2,032,514.444	90			
Corrected total	289,509.494	89			

[a] $R^2 = 0.547$ (Adjusted $R^2 = 0.496$).

were found between zirconia core and resin composite core or resin core ($p = 0.070$ and $p = 0.890$, respectively). Similarly, no significant differences were observed between resin core and resin composite ($p = 0.097$).

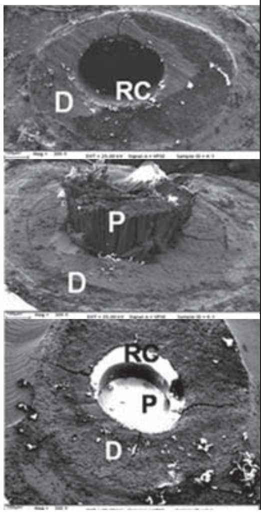
The fracture patterns of all test groups and the corresponding SEM photomicrographs are presented in Figure 3. Failure modes were significantly affected by post types ($p < 0.05$), but not affected by post length ($p = 0.978$) and core materials ($p = 0.757$). While all FRC posts except one post were dislodged from the root canals, all zirconia posts fractured. The majority of fractures in zirconia posts were observed 2 mm below the cervical margin (88.3%). Moreover, the rest of the zirconia posts fractured 2 mm above the cervical margin (12.7%).

Discussion

In the present study, the effects of the length of FRC or zirconia posts restored with two different core materials on fracture strength of endodontically-treated teeth were evaluated. Results obtained within the experimental conditions of the present study indicated that zirconia posts provided higher fracture strength as compared with the FRC groups at both 10- and 15-mm post lengths. Therefore, the first null hypothesis that post material would not affect the fracture strength of endodontically-treated teeth was rejected. The result of the present study is in accordance with the previous study that investigated the effect of esthetic post systems (FRC and zirconia posts) on the fracture resistance of endodontically treated teeth. They found that the fracture strength was significantly affected by the post material [22]. A previous study compared the fracture strength of FRC posts with copy-milled zirconia ceramic posts and found a fracture load of 123.10 ± 19.38 N for FRC, 139.30 ± 2.70 N for copy-milled zirconia posts and 267.10 ± 59.11 N for zirconia posts [3]. Similarly, in the present study, zirconia posts (163.01 ± 5.28) exhibited higher fracture strength values than FRC posts (93.48 ± 7.38). However, a previous study by Mortazavi et al. [22] compared the fracture strength of crowned endodontically-treated teeth restored with three different esthetic posts. They found the mean fracture strength values to be between 678.56 and 573.67 for groups with fiber posts and zirconia posts. A possible explanation for the different fracture strength values observed in these studies might be related with the differences in the testing methods.

Fracture resistance values in teeth rehabilitated with intra-radicular posts could be related with the type and in parallel with the mechanical properties (elastic modulus, strength, flexural resistance) of the post material itself [23]. A previous study by Eraslan et al. [24] investigated the effect of ferrule with different heights on the stress distribution of dentin and the restoration-tooth complex. They observed high stress values at the zirconium oxide ceramic post material. When elastic modulus of the post material is higher, stresses tend to increase within the material. Therefore, stresses located at post material may influence the strength of the post material and the fracture strength values [24].

Beside the overall fracture resistance of endodontically-treated teeth restored with posts, the mode of failure appears to be of interest. The lower fracture strength values of FRC post groups than zirconia post groups could be attributed to the adhesion failures between tooth structure and FRC [1,16]. Additionally, the fracture analysis results clearly indicated the inability of bonding in the FRC groups. With reference to the previous study that demonstrated the negative effects of



	Post type									
	FRC				Zirconia post				One piece zirconia post core	
	Core material									
Post fracture type	Resin core		Resin composite		Resin core		Resin composite			
	Post length									
	10mm	15mm	10mm	15mm	10mm	15mm	10mm	15mm	10mm	15mm
Dislodgement from the root canal	90	100	100	100	0	0	0	0	0	0
2 mm above the cervical margin	90	0	0	0	0	40	30	0	0	0
2 mm below the cervical margin	0	0	0	0	100	60	70	100	100	100

Figure 3. Percentage of fractures in relation to location of fracture according to post type, core material and length. SEM figures above show representative images for each failure mode (D, Dentin; P, Post; RC, Resin cement), original magnification ×300, bar = 100 μm.

surface treatments on bond strength of EverStick post to resin material, the surfaces of posts were not treated with any agents [1]. The FRC post groups showed adhesive failure before occurrence of root/post/core fracture. This result goes like the common belief that flexible posts (fiber-reinforced posts) present more favorable failure modes. Additionally, using fiber posts, whose elastic modulus is in the same range as that of dentine, should preserve teeth from catastrophic failures. Fiber reinforced posts allow teeth to flex under loading, yielding improved stress distribution at the post–cement–dentine interface and into the root itself [16]. Moreover, these posts have a greater ability to absorb stress and a more homogeneous redistribution of stresses to the remaining tooth structure [25].

While almost all of the FRC posts dislodged from the canal except one post, the majority of failures in zirconia posts were catastrophic and occurred 2 mm below or above the cervical margin of the root (Figure 3). In other words, bond failures were not observed with the zirconia posts. The authors speculate that the bond strength of zirconia post to dentin and core material could be higher than the fracture strength of the endodontically-treated teeth restored with the zirconia post. The debonding of the post from the canal might be a clinically more favorable failure mode than fracture of the post. A debonded post could be replaced with another post, whereas a post fracture can only be repaired by completely removing the fractured post.

Previous studies have reported that the reconstructed tooth is subjected to stress conditions mostly in the cervical region [2,24,26]. A previous study compared the fracture strength of two post and core systems using finite element analysis and observed maximum stresses in the cervical region for both of the post systems [27]. Similarly, in the present study, the fracture locations for zirconia posts were predominantly in the cervical region, which may result from a greater concentration of forces in this region due to the angle of the joint between the zirconia post and the core material. Another possible explanation could be that a higher modulus of elasticity of the zirconia post creates a higher stress concentration, thus transferring the stress to the root canal, increasing the fracture potential of the root [2]. Although clinically to remove the zirconia post-core would be extremely difficult, associated with some risk of root perforation and might result in weakening of the root structure, the fracture of posts is more desirable than tooth fractures [28].

A previous study determined the occlusal forces on anterior teeth to be 222 N [29]. According to the values obtained in the present study, all of the systems resulted in lower fracture resistance strength values than this value. Since the failures occurred at lower values than the average occlusal forces reported for anterior teeth, all of them could be considered at risk for failure as a result of normal occlusal forces.

In the present study, increasing the post length in the root canal was not able to increase the fracture strength of endodontically-treated teeth significantly except the one-piece milled zirconia post and core group (group Zr). Therefore, the second null hypothesis that there is no difference between different lengths of posts should be accepted in part. This finding corroborates the results of a previous study, showing that the fracture resistance of teeth restored with FRC posts was not influenced by post length (10 mm and 7.5 mm) within the root canal [30]. Moreover; they concluded that the thickness of glass fiber post is a more important factor than post length.

According to the present results, no significant two-factor interactions were observed between the post length and the post material (p = 0.015). On the contrary, a previous study indicated that a correlation was found between post system and post length on the fracture strength of endodontically-treated teeth crowns with ferrules [18]. A possible explanation could be that the inclusion of a final restoration, such as a crown with ferrule, might affect the fracture strength of the tooth–core build-up and post. In the current study, all specimens were restored and tested with complete-coverage crowns to ensure standardization. However, the effect of ferrule was not investigated in this study. By the exclusion of a final restoration with a ferrule effect (excluding any strengthening effect of the crown) [19], it is possible to solely test the effect of the post length, type and core material.

Additionally, in Group Zr, specimens with a 15 mm post showed higher fracture strength values than specimens with a 10 mm post. This could be attributed to coronoradicular reinforcement by the use of a long one-piece milled post.

Previous studies observed higher fracture strength and restorable fracture modes when resin composite was used with pre-fabricated fiber posts [31,32]. Since the post and core are two separate entities, the flexion of the post under functional forces stresses the post–core interface and results in separation of the core due to permanent deformation of the post [33]. Therefore, in the present study, the fracture strength of endodontically-treated teeth restored with one-piece milled zirconia posts was compared with resin-based core materials. However, the tested core materials had no significant effect on the fracture strength, necessitating acceptance of the third null hypothesis.

Clinical long-term evaluation is crucial and mandatory to a more thorough understanding of the mechanical behavior and reliability of zirconia posts. Furthermore, future studies with thermal cycling and fatigue loading of the specimens are needed to evaluate the longevity of various posts under clinical conditions.

Within the limitations of this *in vitro* study the following conclusions therefore can be drawn:

(1) One-piece zirconia posts or zirconia posts with composite cores had higher fracture resistance than fiber posts. However, a higher restoring success rate can be achieved by fiber posts rather than zirconia posts, according to the restorable failure modes.
(2) In relation to the post length, only one-piece zirconia posts differed significantly in terms of the compressive load required to fracture the root.

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