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Fracture Strength of Endodontically-treated Teeth Restored with Post and Cores and Composite Cores Only

M Özcan • LF Valandro

Clinical Relevance

In teeth with no coronal dentin, metallic posts should be the preferred method over FRC posts or core built-up only. Surface conditioning and the silanization of titanium posts improve attachment of the resin core material to the posts.

SUMMARY

This study compared the fracture strength of different conditioned metallic posts, fiber-reinforced-composite posts and composite cores only in teeth without coronal tooth structure and determined failure modes after the fracture test. Post spaces were prepared in the root canals, and the teeth were randomly divided into seven experimental groups: Gr1: Titanium posts (ParaPost) + Silano-Pen (Bredent) + silane; Gr2: Titanium posts + 30 µm CoJet-Sand (3M ESPE) + silane; Gr3: Titanium posts + 50 µm Al_2O_3+V-primer (Sun Medical); Gr4: Titanium posts+50 µm Al_2O_3 + Alloy primer (Kuraray); Gr5: E-glass FRC post (EverStick); Gr6: Polyethylene fiber (Ribbond) + Resin impregnation and Gr7: Resin composite core only, with no posts. The posts were cemented using Panavia F 2.0 (Kuraray); coronal parts of the roots were etched, primed, bonded and composite cores were built-up. After thermocycling (5°C-55°C, 6000x), the fracture strength test was performed. The fracture strength of titanium posts (408 ± 122 – 550 ± 149 N) was significantly higher (*p*<0.05) than that of FRC posts (321 ± 131 and 267 ± 108 N for Everstick and Ribbond, respectively) or the group without posts (175 ± 70 N) (Gr7) (ANOVA, Tukey's test). The group without posts resulted in complete core detachment (100%). In the E-glass FRC group, 60% adhesive core fracture occurred, covering >1/3 of the core and, in the polyethylene

Mutlu Özcan, Dr med dent, PhD, professor and research associate, University Medical Center Groningen, University of Groningen, Department of Dentistry and Dental Hygiene, Clinical Dental Biomaterials, Groningen, The Netherlands

*Luiz Felipe Valandro, MSc, PhD, associate professor, Federal University of Santa Maria, Department of Restorative Dentistry, Division of Prosthodontics, Santa Maria, Brazil

*Reprint request: R Marechal Floriano, 1184, 97015-372, Santa Maria, Brazil; e-mail: lfvalandro@hotmail.com

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FRC group, 100% post-core detachment at the canal opening was observed. In all the titanium post applied groups (Gr1-Gr4), the posts remained in place with partial detachment of the core material from the post surface at varying degrees, depending on the conditioning method used. When no coronal tooth structure exist, the metal posts showed higher fracture strength values as opposed to the FRC post or no-post approach.

INTRODUCTION

The success of restoring endodontically-treated teeth with prefabricated posts may depend on several factors and/or conditions,[1-2] such as cement medium, post length,[3] type of post,[4-5] remaining coronal dentin,[6-7] high factor of cavity configuration,[8-9] chemical incompatibility between some adhesive systems and resin cements,[10] the heterogeneous nature of the dentin substrate,[11-12] hybrid layer quality in root dentin walls,[13] shape and width of the root canal to access the surfaces to be bonded,[9-14] application technique of the adhesive system into the root canal,[15] fracture strength of the post,[16-17] retention of the post and core build-up.[15]

The fracture strength of the root-post-core assembly is very important to sustain the mechanical stability of the restoration and, therefore, high fracture strength is crucial for clinical success.[16-18] Numerous tests could be performed to assess the mechanical properties of the root post and cores. Whenever an object is exposed to a force, stress is generated within the object to counter the force and keep the object together. Therefore, stress is the response of a material to force. When stress exceeds the cohesive strength of the object, the object breaks.[19] The ability of an object to resist dimensional change under a given stress is related to its stiffness or elastic modulus. The elastic modulus is a good predictor of the ability of a material to resist bending or changing shape. The elastic modulus (E) of dentin is 20 GPa and the elastic modulus of enamel is approximately 80 GPa.[1,19] The elastic modulus, and thereby the fracture resistance of root post and cores, could change, depending on the type of materials used.[1] The optimal modulus of the elasticity of a post in the literature is controversial, and it presents a wide range, depending on the material type ($E_{cast\ gold\ alloys}$= 90 GPa; $E_{titanum}$= 190 GPa; $E_{glass\ fiber}$= 20-40 GPa; $E_{composite}$= 5-25 GPa; $E_{polyethylene\ fiber}$= 2-3 GPa).[1,19] The main advantage to fiber-reinforced composite (FRC) posts is that they flex slightly and, under load, they distribute stresses to the root dentin in a more favorable manner than metal posts.[20-22]

A ferrule of 1.5 mm is desirable but should not be provided at the expense of the remaining tooth/root.[23] However, in some situations after caries removal or in trauma cases, the amount of the remaining tooth structure is not favorable. Currently, resin composite materials could be used as a core build-up material to reconstruct endodontically-treated teeth entirely without conventional crown coverage.[24] In this case, direct core and crown build-up functions as an independent restoration and is considered to be a promising alternative to conventional indirect treatment modalities.[20]

There is still no consensus in the dental literature as to whether resin composite materials or FRC posts could be substitutes for metallic root canal posts.[25-26] Stiffer posts and cores may better support the coronal restoration[27-32] and lead to a more uniform distribution of stress.[33-37] However, they may also result in catastrophic failure modes of the core material if the metal post surfaces are not conditioned.[38] With advances in adhesive technologies, it is possible to condition the metal surfaces for better adhesion of the resin-based core materials and resin cements onto the metals.[39] These methods are not widely studied for metallic posts.[38]

The objectives of the current study were to: 1) compare the fracture strength of metallic posts that were conditioned with various methods versus FRC posts and resin composite built-up only in teeth without coronal tissues and 2) determine failure modes after the fracture test. The studied hypothesis were that the fracture strength of a post-core would be greater than that of core build-up without a post, the fracture strength of a metallic post-core would be greater than that of an FRC post-core and the metallic post-cores would lead to more unfavorable fractures compared with FRC and no-post applications.

METHODS AND MATERIALS

Specimen Preparation

Sound maxillary canine teeth of similar sizes (N=70, n=10 per group) were selected from a pool of recently extracted teeth that were stored in distilled water with 0.1 percent thymol solution at room temperature. The cervical area of the selected teeth had a minimum 4 mm radius that would allow space for bonding the core material and a minimum 12 mm root length for the post.

The root surfaces were cleaned from debris using periodontal scalers. In order to make sure that the enamel was free of crack lines, all the teeth were evaluated under blue light transillumination. The clinical crowns were removed up to 2 mm above the buccal cemento-enamel junction (CEJ). Root canal preparations were made using #2 Gates Glidden drills (Maillefer Dentsply, Baillagues, Switzerland) (ISO size 70) up to 1 mm, followed by #3 drill (ISO size 90) up to approximately 3 mm and a #4 drill (ISO size 110) up to approximately 5 mm away from the apex (4,000 RPM with water cooling). In all roots, 12-mm deep post spaces were prepared as measured from the buccal CEJ. Cylindrical burs (Parapost stainless steel drills; Coltène/Whaledent Inc, Mahwah, NJ, USA) with subsequent diameters of 0.9, 1.14, 1.25 and 1.4 mm were used to prepare the post space (4,000 RPM with water cooling).

The canals were irrigated with 2% NaOCl, thoroughly dried with paper points (Protaper Paper points, Maillefer, Dentsply) and filled with gutta-percha (Protaper Gutta-percha points, Maillefer, Dentsply) and endodontic sealer (AH Plus; Dentsply DeTrey, Konstanz, Germany) with the lateral condensation technique. After 24 hours, the post space preparation was performed with reamers (FRC post steel reamer, apical dimension: 1.0 mm; Ivoclar-Vivadent, Schaan, Liechtenstein) to a length of 10 mm. The specimens were stored in distilled water with a 0.1 percent thymol solution between experimental procedures. The root parts of the teeth were then embedded directly into polymethylmethacrylate (PMMA) (Autoplast, Condular AG, Wager, Switzerland) using plastic rings (PVC, diameter: 2 cm, height: 1 cm) with the flattened occlusal root surface located 2 mm above the acrylic level.

The specimens were randomly divided into seven experimental groups, depending on the post and core type and the conditioning method. Specifications of the conditioning methods and procedures according to each manufacturer's instructions are described in Table 1. Brand name, composition, batch numbers and manufacturers of the materials used are presented in Table 2.

Post Cementation and Core Build-up

In all groups, before cementation of the posts, the root canals were cleaned with 2% NaOCl, rinsed with water for 10 seconds and dried with air for five seconds and paper points. The root canals were then conditioned with ED Primer A + B (Panavia F 2.0, Kuraray Medical, Inc) and applied with a brush. A gentle air flow was used to evaporate the dissolution. The coronal parts were separately etched for 30 seconds with 37% H_3PO_4 (Top Dent, Uppsala, Sweden), primed (Quadrant Unibond Primer, Cavex Holland BV, Haarlem, The Netherlands) and bonded (Quadrant Unibond Sealer, Cavex) according to the manufacturer's instructions. The excess adhesive was removed with absorbent paper points. Resin cement (Panavia F 2.0) was mixed and applied to the post surface and introduced into the canal using a lentulo. Subsequently, the conditioned post was seated in the canal using finger pressure for 10 seconds. Excess cement was removed with a brush, and the cement was light polymerized for 40 seconds (Demetron LC, SDS Kerr, Orange, CA, USA; light intensity: 600 mW/cm^2) from the occlusal surface. The coronal parts of the roots and the resin composite cores (Quadrant Posterior Dense, Cavex) were built-up incrementally, not to exceed 2 mm, using standard polyethylene molds (height: 5 mm, diameter: 3.6 mm) and each layer was light-polymer-

Table 1: *Experimental Groups, Surface Conditioning Methods and Procedures According to Each Manufacturer's Instructions*

Group	Post Type	Surface Conditioning	Silane Coupling Agent/ Metal Primer	Resin Cement
Gr1	Titanium	Chairside air abrasion+heat	Haftvermittle	Panavia F 2.0
Gr2	Titanium	Chairside silica coating	ESPE-Sil	Panavia F 2.0
Gr3	Titanium	Chairside air abrasion	V-Primer	Panavia F 2.0
Gr4	Titanium	Chairside air abrasion	Alloy Primer	Panavia F 2.0
Gr5	E-glass fiber	-	-	Panavia F 2.0
Gr6	Polyethylene fiber	Bonding agent	-	Panavia F 2.0
Gr7	No post, composite buildup	-	-	-

Group 1–Chairside air-abrasion with 50 µm alumina particles (Korox, Bego, Bremen, Germany) using an intra-oral air-abrasion device (Dentoprep, Ronvig, Denmark), holding the nozzle perpendicular to the surface from a distance of approximately 10 mm for 15 seconds/cm² at a pressure of 2.3 bar. The substrate surface was rinsed for 20 seconds and air-dried for 5 seconds. The heat treatment was achieved applying the flame of Silano-Pen (Bredent, Senden, Germany) 5 seconds/cm² at the surface; the surface was allowed to cool down to room temperature and the corresponding silane (Haftvermittler, Bredent) was applied to the surface with a disposable brush and 3 minutes later any reaction was noted.

Group 2–Chairside silica coating with 30 µm alumina particles coated with silica (CoJet-Sand, 3M ESPE, Seefeld, Germany) holding the nozzle perpendicular to the surface from a distance of approximately 10 mm for 13 seconds/cm² at a pressure of 2.8 bar. MPS silane (ESPE-Sil, 3M ESPE) was applied to the surface with a disposable brush and five minutes later any reaction was noted.

Group 3–Chairside air-abrasion with 50 µm alumina particles (Korox, Bego, Bremen, Germany) using an intra-oral air-abrasion device (Dentoprep, Ronvig, Denmark), holding the nozzle perpendicular to the surface from a distance of approximately 10 mm for 15 seconds/cm² at a pressure of 2.3 bar. The substrate surface was rinsed for 20 seconds and air dried for 5 seconds. Two coats of V-Primer was applied to the surface with a sponge pellet.

Group 4–Chairside air-abrasion with 50 µm alumina particles (Korox, Bego, Bremen, Germany) using an intra-oral air-abrasion device (Dentoprep, Ronvig, Denmark), holding the nozzle perpendicular to the surface from a distance of approximately 10 mm for 15 seconds/cm² at a pressure of 2.3 bar. The substrate surface was rinsed for 20 seconds and air-dried for 5 seconds. Alloy Primer was applied to the surface with a disposable brush.

Group 5–E-glass fiber post at the right length was placed in the canal and light polymerized for 40 seconds.

Group 6–Two bundles of polyethylene fibers were impregnated with adhesive resin (Quadrant Unibond) and light-polymerized for 40 seconds.

Group 7–Resin composite (Quadrant Posterior Dense) was packed into the canal and in the mold incrementally and each layer was light polymerized for 40 seconds.

Table 2: *Brand Name, Composition, Batch Numbers and Manufacturers of the Materials Used*

Brand Name	Composition	Batch #s	Manufacturer
Parapost XP	Titanium	11	Coltene/Whaledent Inc, Mahwah, NJ, USA
Haftvermittler	3-methacryloxypropyltrimethoxysilane (MPS), Ethanol	68411	Bredent, Senden, Germany
ESPE-Sil	3-methacryloxypropyltrimethoxysilane (MPS), Ethanol		3M ESPE, Seefeld, Germany
V-Primer	6-(4-vinylbenzyl-n-propyl)amino-1,3,5-triazine-2,4-dithiol, -dithione tautomer (VTD) in acetone	KK1	Sun Medical Co LTD, Shiga, Japan
Alloy Primer	6-(4-vinylbenzyl-n-propyl)amino-1,3,5-triazine-2,4-dithiol, -dithione tautomer (VTD) and 10-methacryloxydecyl dihydrogen phosphate (MDP) in acetone	00494A	Kuraray Medical, Inc, Osaka, Japan
Quadrant UniBond Primer	Ethanol, (2-hydroxyethyl)-methacrylate, maleic acid		Cavex Holland BV, Haarlem, The Netherlands
Quandrant UniBond Sealer	Poly-functional methacrylate-based monomers 2.5%w, Bis-GMA, UDMA, TEG-DMA 22%w, barium aluminum silicate glass fillers, mean 5 µm 14%w, Barium, aluminum, silicate glass fillers, mean 0.7 µm 43%w, porous SiO_2, mean 8 µm 18%w, polymerization catalysts 0.4%w, inorganic pigments 0.1%w		Cavex Holland BV, Haarlem, The Netherlands
Everstick Post	E-glass fiber	2060403	StickTech, Turku, Finland
Ribbond	Ultra-High Molecular Weight Polyethylene	9549	Ribbond, Seattle, WA, USA
Quadrant Posterior Dense	Bis-GMA		Cavex Holland BV, Haarlem, The Netherlands
Panavia F 2.0	10-methacryloxydecyldihydrogen-phosphate (MDP) Paste A: BPEDMA/MDP/DMA Paste B: Al-Ba-B-Si glass/silica containing composite	41144	Kuraray Medical, Inc, Osaka, Japan

ized for 40 seconds. Since the length of the coronal part of the posts was kept to 3 mm, the polyethylene mold allowed for approximately a 2-mm thickness for the core material above the post material. The diameter of the whole composite core covering the post material was 3.6 mm. The entire length of the post was 10 mm and the diameter was 1.4 mm.

The polyethylene molds were then gently removed. A polyethyleneglycol/glycerin oxygen inhibition gel (Oxyguard II, Kuraray, Medical Inc, Osaka, Japan) was applied around the margins of the core-dentin interface. After three minutes, the oxygen inhibition gel was rinsed thoroughly. All specimens were kept at 37°C for 24 hours, then subjected to thermocycling for 6000 cycles between 5°C and 55°C in deionized grade 3 water (Willytech, Gräfelfing, Germany). The dwelling time at each temperature was 30 seconds and the transfer time from one bath to the other was two seconds.

Fracture Strength Test

The specimens were placed in a jig of the universal testing machine (Zwick ROELL Z2.5MA, 18-1-3/7, Zwick, Ulm, Germany). In order to simulate the clinical situation as closely as possible, the specimens were mounted to a metal base and load was applied from the buccolingual direction on the axial-occlusal corner of the core with the load direction almost perpendicular to the post axis (135°). This angle was chosen to simulate the load in the mouth during chewing.[15-17] The crosshead speed was 0.5 mm/minute. The maximum force to produce fracture was recorded. After the fracture test, the failure sites were examined by two calibrated operators both visually and from digital photographs at 20x magnification using a software program (CorelDRAW 9.0, Corel Corporation and Coral Ltd, Ottawa, Canada). The failure types were categorized as failures of the core materials covering the post >1/3 or <1/3, with the post being in place, loss of post retention, post fracture or tooth fracture. Upon disagreement, a consensus was reached.

Statistical Analysis

Statistical analysis was performed (SAS System for Windows, release 8.02/2001, Cary, NC, USA) and the bond strength data were analyzed by one-way analysis of variance (ANOVA). Due to the significant difference among the groups ($p<0.001$), multiple comparisons were made using Tukey's adjustment test. *P*-values less than 0.05 were considered to be statistically significant in all tests.

RESULTS

One-way ANOVA showed significant influence of the post type on fracture strength (p<0.0001) (Table 3). The fracture strength of the titanium posts (408 ± 122 – 550 ± 149 N), with Group 3 being the highest, was significantly greater (p<0.05) than those of the FRC posts (321 ± 131 and 267 ± 108 N for Everstick Post and Ribbond, respectively) or the no-post group (175 ± 70 N) (Group 7) (ANOVA, Tukey's test).

The group without posts resulted in 100% core detachment at the post-hole opening. In the E-glass FRC group, 60% adhesive core fracture covered >1/3 of the core and, in the polyethylene FRC group, 100% post-core detachment at the post-hole opening was observed. In the titanium post-applied groups (Groups 1-4), the posts remained in place with partial detachment of the core material from the post surface at varying degrees, depending on the conditioning method used. Core material detachment was observed the least in the V-primer applied group. Categorization and incidence of failure types are displayed in Table 4. Figure 1a-e shows the representative images of the fractured specimens from all the experimental groups.

DISCUSSION

The remaining intact coronal tooth tissue improves the fracture strength[7] and clinical success[1] of teeth restored with root posts. In the current study, in order to simulate scenarios, such as trauma cases or the removal of caries extending towards the CEJ, the coronal parts of the teeth were removed and the fracture strength of the posts were tested.

The principal function of a root post is to stand the core material, especially in crownless teeth. Chewing forces create direct stress on the root post. Hence, the post must be stiff to resist the load, but it must not be too stiff to increase the fracture risk of the dental root. The important clinical question that remains to be answered is: What is the ideal elastic

Table 3: *The Mean (SD ± standard deviations) Fracture Strength Values (N) of the Experimental Groups*

Groups	Mean ± SD (N)
Gr 1	521 ± 153[a]
Gr 2	525 ± 91[a]
Gr 3	550 ± 149[a]
Gr 4	408 ± 122[a,b]
Gr 5	321 ± 131[b,c]
Gr 6	267 ± 108[b,c]
Gr 7	175 ± 70[c]

**The same superscripted letters indicate no significant differences (Tukey's test, α=0.05). See Table 1 for group descriptions.*

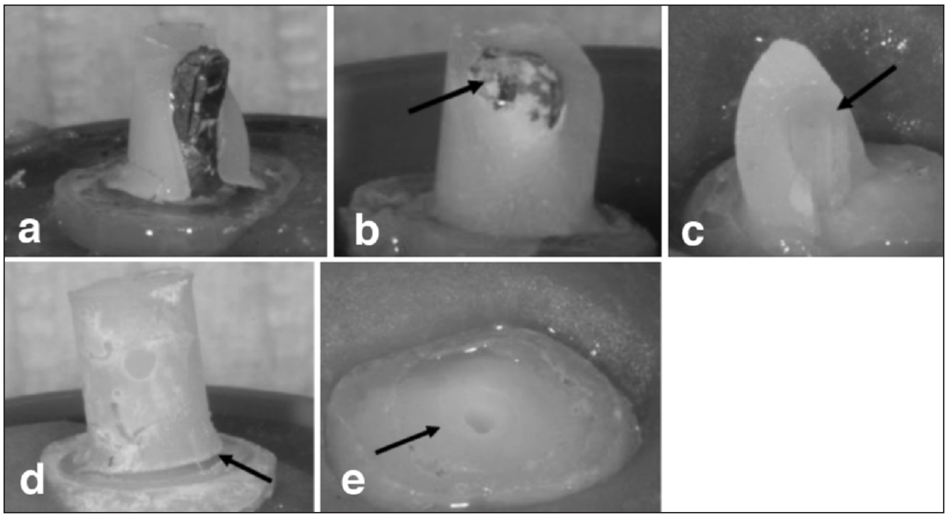

Figure 1. *Representative images of the failure types observed a) Partial adhesive core fracture with the metal post remaining intact in the canal, b) Minimal amount of adhesive core fracture with the metal post remaining intact in the canal, c) Partial adhesive core fracture between the E-glass fiber and the core material, with the post remaining intact in the canal, d) Loss of post and core retention at the canal opening, e) Complete detachment of the composite core at the canal opening. See Table 1 for group descriptions.*

Table 4: *Incidence (percent) of Favorable and Unfavorable Failure Types Per Group*

	Favorable Failures				
	>1/3 Core Fracture	<1/3 Core Fracture	Loss of Post Retention	Post Fracture	Tooth Fracture
Gr 1	40	60	0	0	0
Gr 2	60	40	0	0	0
Gr 3	20	80	0	0	0
Gr 4	80	20	0	0	0
Gr 5	60	40	0	0	0
Gr 6	0	0	100	0	0
Gr 7	100*	0	0	0	0

**Adhesive core fracture with complete detachment of the composite core at the canal opening.*

modulus for a root post? Some previous studies have stated that fiber posts are excellent alternatives to metal posts, because they create less damage to the root due to their similar modulus of elasticity to dentin.[1,16-17] Fracture strength studies showed that tooth fractures were "favorable" when they were restored with fiber posts; the fiber post failed and the root remained intact at lower fracture strength values.[27-32]

The current study noted that the metal post groups had the highest resistance to fracture when compared to the fiber post or no-post groups. The mean fracture strength results, which range between 408 ± 122 – 550 ± 149 N for metallic posts and no-posts (175 ± 70 N), were lower than that reported in a recent study (1386 ± 598 N for metal posts and 1716 ± 304 N for no-posts).[20] This could be attributed to the fact that the current study concentrated on the fracture strength results of post cores alone, without incorporation of the crown. It should also be noted that the crosshead speed used in the current study was 0.5 mm/minute, whereas, in the study by Fokkinga and others,[20] it was 5 mm/minute, which might have led to variations between the results.

Post fracture and root fracture can be considered unfavorable failures since, usually, the former results in difficult retrieval of the posts, especially metallic ones, and the latter may require extraction. The failure types observed were not in accordance with some other studies.[27-32] It is important to consider that, during the experiments, the loading was stopped immediately when the core material failed. It appears reasonable that, if the loading had been continued, the root probably would have fractured. When *in vitro* studies in the field of post and cores are compared, the set-up of the testing procedures should be also taken into consideration. Based on studies showing stress distribution using Finite Element Analysis, it was reported that the effect of stress concentration on root canal walls with the utilization of rigid posts (elastic modulus up to 100 GPa) would increase the risk of root fracture.[32-37] On the other hand, flexible posts with an elastic modulus of approximately 50 GPa allow for a more uniform stress distribution in the root, thus reducing the fracture risk of the remaining tooth structure, especially after long-term mechanical cycling.[27-32]

The results obtained in the current study from fiber posts were less favorable compared to metal posts with regard to fracture strength. Although the fiber posts tested did not show significant differences in fracture strength, the failure types presented differences with the fiber posts. In the E-glass fiber group, the fiber post remained intact in the root canal and the core material was partially detached from the fiber. However, in the polyethylene fiber post group, the failures were exclusively loss of post-core retention at the post-hole opening. It was evident that the polyethylene fibers were not able to support the covering resin core material.

Possible root fractures associated with the use of metal posts, as a consequence of fatigue or simply due to incompatibility of the elastic modulus between the dentin and metal, can be overcome by not using a post, only a composite core. Restoring the endodontically-treated teeth without a post would certainly serve as a conservative approach. Unfortunately, the results of the current study were not favorable with this approach in terms of both fracture strength and failure types. Therefore, the first and second hypotheses were accepted. However, due to no incidence of catastrophic failures in the metallic post groups, the third hypothesis was rejected.

The fracture strength of root posts cemented adhesively into the root canal can minimize the risk of root fracture. Based on the results of the current study, in the case of crownless teeth, the use of root post anchorage appears to be mandatory. The metal post and E-glass fiber post systems seem to allow for better mechanical resistance. It is essential to clarify that, in general, root and/or restoration fracture occurs clinically after long-term service due to cyclic loading.[1] Therefore, *in vitro* tests employing static compressive forces would help researchers to screen the performance of materials or systems in a quicker time period compared to the fatigue tests. However, the results of the current study still need to be verified under fatigue tests. Usually, a silicone layer is used as a shock-absorbing layer around the roots in order to simulate the periodontal ligament. In the current study, the periodontal ligament surrounding the root was not simulated. This was due to the results of a study where it was claimed that the periodontal ligament simulation approach may have some importance in fatigue studies but not for static loading.[20]

Although surface conditioning methods have been widely employed in cementation or in the repair of fixed partial-dentures, they are not commonly applied for the conditioning of posts prior to adhering the core material. In this study, when V-Primer was used, the majority of failures were in the form of partial adhesive fractures of the core material covering <1/3 of the core surface. Clinically, such failures could easily be repaired without necessitating removal of the post. During the experiments, regardless of the post type, in some specimens, the top part of the core composite was observed to fracture first in the form of chipping, then the fracture propagated. This indicates that, although the core resin diameter was standardized using a mold, in situations where the post diameter is greater than the ones tested, the failure type may differ.

The non-significant difference among the groups with metallic posts indicates that the silane-coupling agents and the alloy primers react well with the surface hydroxyl groups created after chairside air-abrasion either with alumina or silica particles. Clinicians should consider using such conditioning systems not only for conditioning the cementation surfaces of the posts but also for the coronal parts, so that the resin core material could adhere better to the metal posts.

CONCLUSIONS

Based on the current study, the following can be concluded:

1. When no coronal dental tissues exist, it is essential to use a post and preferably a metallic post for additional retention.
2. Surface conditioning and silanization of titanium posts resulted in better attachment of the resin core material onto the metallic posts.
3. When failure types were evaluated, the use of polyethylene fiber post or core build-up only was less favorable compared to glass fiber or metallic posts.

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