

# Fracture Resistance of Endodontically Treated Teeth: Effect of Tooth Coloured Post Material and Surface Conditioning

Muhittin Toman\*, Suna Toksavul\*, Mehmet Sarıkanat†, İbrahim Nergiz\* and Petra Schmage\*

**Abstract** - This *in vitro* study evaluated the effects of the different endodontic posts and surface conditioning on the fracture resistance and fracture modes of endodontically treated teeth. The experimental groups consisted of zirconia ceramic post with a glass-ceramic core [A], zirconia ceramic post with a composite core [B], glass fiber composite post (FRC) with a composite core [C], and titanium post with a composite core [D]. All posts in these groups were cemented with self-adhesive resin cement (Rely X Unicem Aplicap) combination with tribochemical silica coating (TSC). Groups E, F, G and H comprised the same post-and-core materials as the first 4 groups but cemented with the same resin cement without TSC. Specimens were subjected to thermal cycling between 5°C and 55°C for a total of 5000 cycles with 30s per cycle. Static load was applied to the palatal surface of each specimen until they were fractured. Statistical analysis was conducted using analysis of variance (ANOVA) followed by post-hoc comparisons (Tukey). The fracture resistance was significantly affected by the post material ( $P < 0.001$ ) and surface conditioning ( $P < 0.001$ ; two-way ANOVA). The application of TSC to post surface decreased the fracture resistance of zirconia ceramic post with composite core ( $p=0.002$ ; Tukey) and glass FRC post with composite core ( $p=0.029$ ; Tukey). No catastrophic failure was observed for groups B, C, D, E, F and G. Under the testing conditions used, the titanium post/composite core that had been silicoated exhibited the highest fracture resistance.

KEY WORDS: endodontically treated tooth, surface conditioning, tooth coloured post, tribochemical silica coating

## INTRODUCTION

Increasing aesthetic demand of patients and dentists led to the development of several all-ceramic crown systems with characteristics similar to natural teeth, such as translucency and fluorescence<sup>1-3</sup>. However, the use of metal alloy posts and cores under the all-ceramic crowns can lead to aesthetic problems. Metal alloy posts and cores produce a grey discoloration of translucent all-ceramic crowns because light transmission is impeded by metallic posts limiting the aesthetic appearance of all-ceramic crowns. To ensure a satisfactory aesthetic result, the post-and-core system would need to be tooth-coloured, reflecting and transmitting light in a manner similar to a natural tooth<sup>4</sup>.

The use of posts in endodontically treated teeth is still questionable. Recent *in vitro* studies indicated that posts did not increase the fracture resistance of endodontically treated teeth and posts should be used only to retain the core when there is not enough retention for the artificial crown<sup>5-7</sup>. The preparation of a post hole in an intact endodontically treated tooth may weaken such a tooth. In this respect, remaining tooth structure is a key factor. Intact endodontically treated teeth can be restored with filling material without post-and-core restorations<sup>8,9</sup>. In the case of substantial horizontal loss of the clinical crown, there

is no restorative alternative other than fabricating a post-and-core buildup<sup>10</sup>.

A variety of tooth-coloured post materials such as zirconia ceramic and glass FRC are available for the restoration of endodontically treated teeth but there is no consensus on which material is best suited for clinical use. Glass FRC post systems were composed of unidirectional glass fibers in the resin matrix that strengthened the structure of the post without compromising the modulus of elasticity<sup>11</sup>. The main advantage of glass FRC posts is their modulus of elasticity to be close to that of dentine. In addition, they can be easily removed from the root canal when a failure occurs. Zirconia ceramic posts are very stiff and this may lead to tooth fracture<sup>14</sup>. It should be noted that removing a zirconia ceramic post from root canal is almost impossible when it fractures. On the other hand, it was reported that zirconia ceramic resisted bending forces more than titanium and glass FRC due to a higher modulus of elasticity. Thus, a zirconia ceramic post is loaded more frequently than titanium and glass FRC and stress acting on the dentine decreased<sup>15</sup>.

The CoJet system is a chairside system with an intraoral airborne-particle-abrasion device; the system includes a tribochemical coating of the surface with silica-modified aluminum-oxide particles (CoJet Sand) followed by silanization (ESPE Sil). By sandblasting with silicate-coated alumina particles, a silicate layer is welded onto the surface by high spot heat produced by blasting pressure in a process referred to as tribochemical coating. Sandblasting is followed by silanization, and the CoJet system thus combines micro-mechanical retention pro-

\* DDS, PhD

† PhD

duced by sandblasting and chemical bonding resulting from silanization of the silicated surface. Several *in vitro* studies were designed to evaluate the effect of tribochemical silica coating on the bond strength between zirconia post and resin cement<sup>16-20</sup>. According to those studies, the bond strength of resin cement to titanium, glass FRC and zirconia ceramic posts was significantly increased after conditioning of the post surface with CoJet system.

The purpose of this *in vitro* study was to evaluate the effects of the different endodontic posts and surface conditioning on the fracture resistance of endodontically treated maxillary central incisors with extensive loss of tooth structure. The null hypothesis to be tested was that fracture resistance of endodontically treated tooth do not vary with post material and surface conditioning.

## MATERIALS AND METHODS

A total of 80 human maxillary central incisors free of cracks, caries and fractures were used in this study. All external debris were removed with an ultrasonic scaler and the teeth were stored in saline solution at 4°C and used within 3 months following extraction. Bucco-palatal and mesio-distal dimensions at cemento-enamel junction and root lengths of all teeth were measured with a digital caliper (Absolute Digimate Calipers), so that teeth of similar dimensions could be evenly distributed between control and test groups. Teeth with curved roots and wide or atypically shaped root canals, and/or roots shorter than 16 mm were excluded. Coronal sections of teeth were removed using low speed diamond saw (EXAKT Apparatebau) under water cooling at the level of the cemento-enamel junction and perpendicular to the long axis of the teeth. The root canals were then shaped to an size 60 using Hedström files (Dentsply Maillefer, Ballaigues, Switzerland). After irrigation with 2.5% sodium hypochlorite (NaOCl) the canals were dried with paper points (Roeko, Langenau, Germany). Each root canal was filled using lateral compaction method with gutta-percha points (VDW, Munich, Germany) and sealer (AH Plus; Denstply, Konstanz, Germany). The roots were stored at 37°C in distilled water for 1 week.

Prior to post placement, gutta-percha was removed from the root canals with Gates Glidden burs, leaving 3 mm of root filling in the apical portion. The root canals were then prepared with a tapered No.2 drill (ISO 90) of the same diameter and shape as the post that was available in the Komet ER post kit. A length of 12 mm was ensured for each post hole in each root canal. A 1 mm deep central inlay cavity was prepared in a rotation-protecting oval shape, leaving a minimum dentine thickness of at least 1.5 mm using a special drill 2.5 mm in diameter in ER post system. Root canal was roughened using the diamond roughening instrument of the post system (Fig. 1). The post spaces were then irrigated with 2.5% sodium hypochlorite intensively and dried with paper points.

Having standardized the post preparations, the previously recorded buccolingual and mesiodistal measurements taken at the cemento-enamel junction of each tooth were used to ensure that each of the eight groups of 10 teeth had comparable dimensions. Groups, materials and their composition were given in Table 1. These eight groups were then randomly assigned.

In group A, zirconia ceramic posts (Cerapost) were fitted into the root canals, and a core pattern was built up with an autopolymerizing acrylic resin (Pattern Resin LC). The acrylic patterns were prepared to the desired shape with a low-speed rotary instrument. To standardize the dimension of the acrylic patterns, a silicone stent was used. The same silicone stent was used for all teeth in all groups in order to facilitate construction of standard composite cores. In this way all composite cores were of similar dimensions. The post-and-core patterns were then sprued and invested (IPS Empress Investment). The cores were heat-pressed from zirconia-enriched glass-ceramic (Empress-Cosmo) directly onto the pre-fabricated zirconia ceramic posts at 900°C and 5 bars pressure. Investment was removed, all surfaces were carefully air abraded. In all groups, posts were cemented into the root canals with a self-adhesive dual-cure luting resin cement (RelyX Unicem Aplicap). The zirconia post surfaces and the bottom surfaces of the ceramic cores were conditioned using the intraoral air abrasion device (RONDOflex 2013) at 2.8 bar pressure from a distance of



**Figure 1.** ER post system. Dentinpost (A), Cerapost (B), Titanpost (C), drill for preparation of post space (D), drill for preparation of inlay cavity (E), roughening instrument (F).

**Table 1** Groups and composition of the materials used in this study

Groups	Post Material Composition of post (Per cent by weight) [Batch #]	Core material	Composition of core (Batch #)	Luting system	Composition of luting system (Batch #)
A	Zirconia ZrO <sub>2</sub> +Y <sub>2</sub> O <sub>3</sub> > (99) [232112]	Heat-pressed ceramic	Cosmo ingot SiO <sub>2</sub> , ZrO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , P <sub>2</sub> O <sub>5</sub> , Li <sub>2</sub> O, Na <sub>2</sub> O, K <sub>2</sub> O, F and pigments (F59054)	Rely X Unicem Applicap with CoJet	Rely X Unicem Applicap (56818) bifunctional methacrylate, multifunctional phosphoric acid methacrylates, alkaline filler CoJet Sand: sand 30µm grit consisting of aluminumoxide (68411) Silane: 3-methacryloxypropyltrimethoxy silane in ethanol (68300)
B	Zirconia	Dual-cure composite Dentin bonding agent	Rebilda DC (Dual-cure composite) Base: BisGMA, UDMA, TEGDMA, catalyst CQ, Amine, fillers(421040) Catalyst: BisGMA, UDMA, TEGDMA, catalyst BPO, fillers (421040) Solobond Plus (Dentin bonding agent) Solobond Primer: Maleic acid, hydrophilic methacrylates, polyfunctional monomers, acetone, water (411428) Solobond Adhesive: Hydrophilic methacrylates, polyfunctional monomers, acetone (411427)	Rely X Unicem Applicap with CoJet	
C	Glass FRC Glass fibres (60), Epoxy resin (40) [355TL12]	Dual-cure composite Dentin bonding agent		Rely X Unicem Applicap with CoJet	
D	Titanium Pure titanium [49L12]	Dual-cure composite Dentin bonding agent		Rely X Unicem Applicap with CoJet	
E	Zirconia	Heat-pressed ceramic		Rely X Unicem Applicap without CoJet	
F	Zirconia	Dual-cure composite Dentin bonding agent		Rely X Unicem Applicap without CoJet	
G	Glass FRC	Dual-cure composite Dentin bonding agent		Rely X Unicem Applicap without CoJet	
H	Titanium	Dual-cure composite Dentin bonding agent		Rely X Unicem Applicap without CoJet	

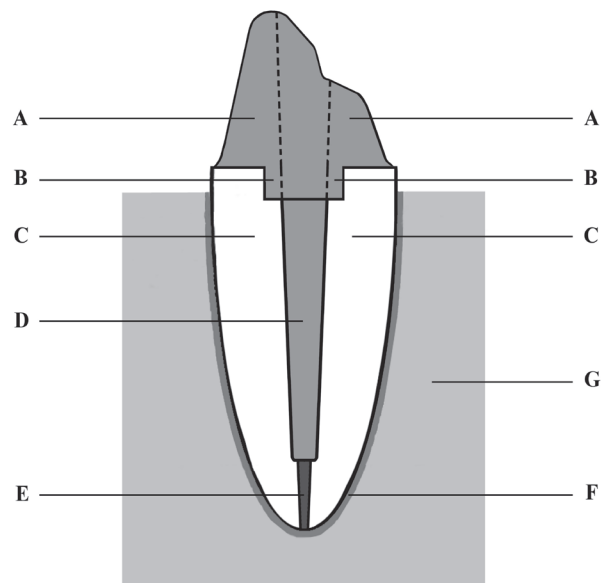
approximately 10 mm for about 15 seconds with 30- $\mu$ m silicon oxide (CoJet-Sand) while rotating the post manually until its surface appeared matte under visual inspection followed by silanization (ESPE Sil). The RelyX Unicem Capsule was activated in the Aplicap Activator (3M ESPE), followed by 10 seconds of mixing in a high-frequency mixing unit (RotoMix). The capsule was inserted in the Aplicap Applier (3M ESPE), and the self-adhesive cement was applied to the post surface. Zirconia ceramic post-and-ceramic core was then inserted into the post space. After removal of excessive cement, the self-adhesive resin cement was light-cured for 40s.

In group B, after the try-in procedure of the zirconia ceramic posts (Cerapost) in the root canals, each post was cut to a length of 3 mm coronal to the preparation. The cementation procedures of the zirconia ceramic posts were performed as in group A. Core was built-up with a dual-curing composite core material (Rebilda DC) and an appropriate dentine bonding agent (Solobond Plus) according to the manufacturer's instructions. Composite core material was not light-polymerized. Coronal portion of the post was also tribochemical silica coated with CoJet system as mentioned in group A before the construction of the composite core.

In group C, glass FRC posts (Dentinpost) were tried in the root canals and cemented as in group A. Core was built-up as in group B. In group D, titanium posts (Titanpost) were tried in the root canals and cemented as in group A. Core was built-up as in group B. In group E, the try-in procedure of the zirconia ceramic posts and fabrication of ceramic cores directly onto zirconia ceramic posts were performed and cemented as in group A without application of the CoJet system. In group F, zirconia ceramic posts were tried in the root canals and cemented as in group A without application of the CoJet system. Core was built-up as in group B. In group G, glass FRC posts were tried in the root canals and cemented as in group A without application of the CoJet system. Core was built-up as in group B. In group H, titanium posts were tried in the root canals and cemented as in group A without the application of CoJet System. Core was built-up as in group B.

Specimens were subjected to thermal cycling between 5°C and 55°C for a total of 5000 cycles with 30s per cycle. Root surfaces were then marked 2 mm below the cemento-enamel junction to simulate the biologic width<sup>21</sup> and covered with wax in 0.3 mm in thickness wax. Specimens were stabilized on a fixator (Herbst) with vertically moving rods, from the most coronal tip of each core, with sticky wax. Specimens were then embedded in autopolymerizing acrylic resin (Meliodent) surrounded by a plastic mould. After the first signs of the polymerization, specimens were removed from the resin blocks, and the waxes on the root surfaces were removed using a hand instrument. Polyvinylsiloxane impression material (Affinis) was injected into resin base, and the specimens were reinserted into resin base. Standardized silicone layers that simulated periodontal ligament were created (Fig. 2)<sup>22,23</sup>. All specimens were stored in a condition of 100% humidity at 37°C for 24 h prior to the fracture test. In order to distribute the force evenly and to avoid peaks a 0.3 mm thick tin foil was placed between the specimen and the loading die.

Specimens were mounted in a universal load-testing machine (Schimadzu AG-50 kNG) and were loaded un-



**Figure 2.** Schematic drawing of specimen mounted in acrylic resin block: core (A), Inlay cavity (B), root dentine (C), prefabricated post (D), apical root filling (E), silicone simulated periodontal ligament (F), resin block (G).

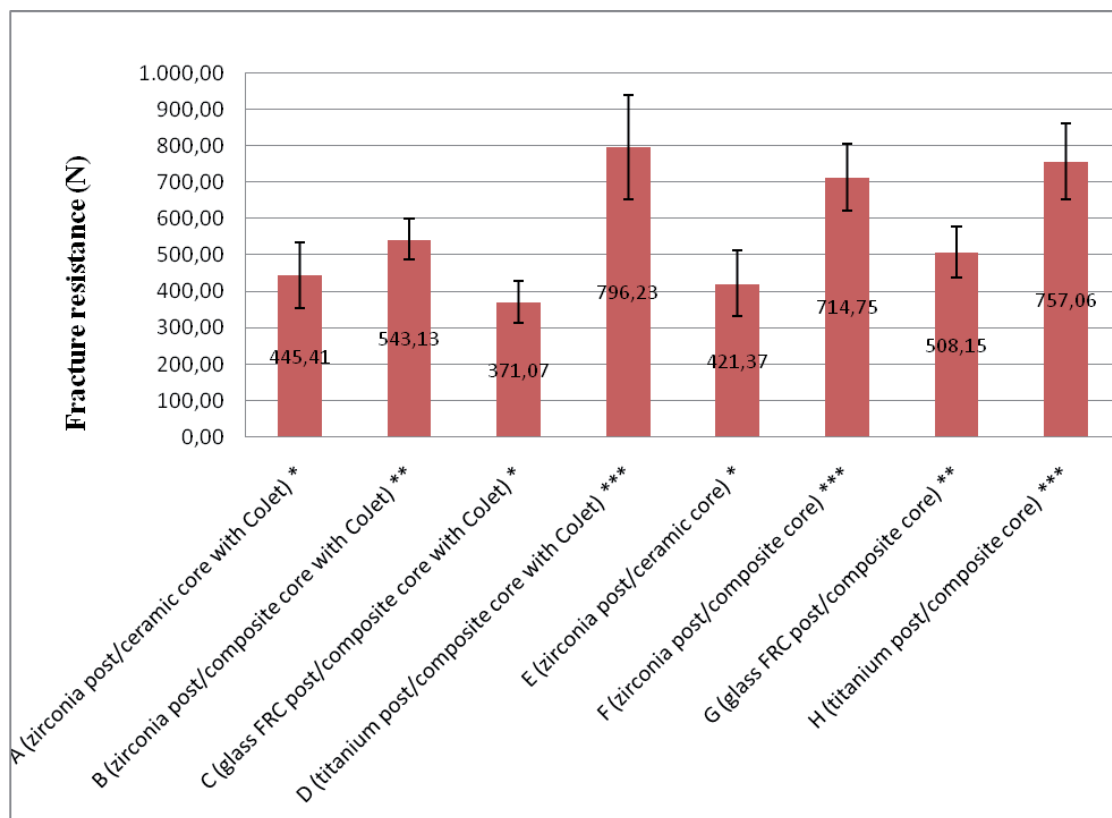
til fracture at a cross-head speed of 0.5 mm/min. The force was applied with an angle of 135° 2 mm below the incisal edge on the palatal surface of cores using a steel ball with 6 mm diameter. Fracture loads were determined, and the modes of fracture were also recorded and classified as repairable if located in the cervical third of the roots and catastrophic if located below<sup>23</sup> by visual inspection with the aid of trans-illumination. All statistical analyses were performed using commercially available software (SPSS for Windows 15.0). A two-way anova was applied with fracture resistance as the dependent variable, and the post material and surface conditioning as factors. The influence of post material and surface conditioning on fracture resistance was analysed using a two-way analysis of variance (two-way ANOVA). The Tukey test was used for post hoc multiple comparisons. The level of significance was 0.05.

## RESULTS

Mean fracture resistances associated with post material and surface conditioning for all groups were given in Figure 3. The fracture resistance was significantly affected by the post material ( $P < 0.001$ ) and the surface conditioning ( $P = 0.004$ ; two-way ANOVA). There were significant interactions between two co-variables (post material and surface conditioning) ( $p < 0.001$ ) (Table 2).

There was no significant improvement in the fracture resistance of endodontically treated tooth for titanium post with composite core after the application of tribochemical silica coating ( $p=0.98$ ). Conversely, the factor tribochemical silica coating decreased the fracture resistance of endodontically treated tooth for glass FRC post/composite core ( $p < 0.05$ ) and zirconia ceramic post/composite core ( $p < 0.05$ ).

Zirconia ceramic post and ceramic core with CoJet (A) showed 2 catastrophic failures at the middle region of the root. Titanium post and composite core without CoJet (H,



\*Groups with same superscript exhibited no significant difference at  $p > 0.05$

**Figure 3.** Summary of fracture resistance with combinations of post material and surface conditioning

positive control) displayed 1 catastrophic failure at the apical region of the root. The other groups showed repairable failure at cervical region of the root. All groups except for groups A, B, E and F (zirconia ceramic post groups) showed no fractures at the root or post. (Table 3)

## DISCUSSION

This study compared the fracture resistance of the endodontically treated maxillary central incisors restored with ERpost system (zirconia ceramic post, Cerapost; glass FRC post, Dentinpost; titanium post, titanpost). Extracted human teeth were used for the preparation of the test specimens. Human teeth have been commonly used for the in-vitro testing of post restorations<sup>23,24</sup>. The main disadvantage of using of human teeth is relatively large variation in size and mechanical properties<sup>25</sup>, often resulting in large standard deviations. In addition, dentinal changes can be caused by different water content, pulpal condition before tooth extraction, patient age, and composition of dentine. These variations can affect the fracture pattern during loading. On the other hand, artificial roots cannot mimic natural dentine and their adhesion to the post is unrealistic and not similar to the clinical situations<sup>26</sup>. Strub et al<sup>27</sup> reported that higher fracture loads were observed with natural test teeth than with artificial roots. In this study, special care was taken in selection process of natural teeth in same size.

All posts having the same sizes and same shapes were luted with the same adhesive free resin cement in this study. All the teeth used in this study were sectioned 16 mm coronal

to the most apical point, so post length for all groups was standardized. Special care was taken to standardize the dimensions of core. Thus, the effects of post material and tribochemical conditioning of post surface on the fracture resistance of endodontically maxillary central incisors were evaluated and any other variations were eliminated.

In this study, conical posts were used. It is known that parallel sided posts are more retentive than any other design. However, the use of them increases stress concentration in dentine at the apical part of the posts as they leave a thin dentinal wall at that region, and increases the risk of perforation and fracture<sup>28</sup>. Tapered posts exhibit lower concentrations of stress in the apical portion; therefore, they decreased the risk of catastrophic fracture<sup>29</sup>.

In some studies, it was concluded that coronal dentine above the shoulder significantly increased the fracture load of endodontically treated teeth received post-and-core restoration<sup>30,31</sup>. In this study, coronal dentine above the preparation margin was not left because, natural teeth were sectioned at the cemento-enamel junction to simulate the substantial horizontal loss of the clinical crown. In this situation, there is no alternative solution to fabricating a post-and-core build-up. The preparation of post hole in an intact endodontically treated tooth may weaken such a tooth. In this respect, such a tooth can be restored with filling material without post-and-core restoration<sup>10</sup>. Since the ferrule effect would not be obtained, the crown restorations were not performed. It is true that a crown creates a ferrule effect and different load distribution when placed over a core buildup if the margins encircle a

**Table 2.** Results of two-way ANOVA

Source	Sum of Squares	df	Mean Square	F-value	P value
Post type	1636793.313	3	545597.771	64.141	0.000
Surface conditioning	75322.47	1	75322.47	8.855	0.004
Post type × Surface conditioning	176470.946	3	58823.649	6.915	0.000
Error	612449.042	72	8506.237		
Total	28461114.2	80			
Corrected Total	2501035.771	79			

**Table 3.** Mode and distribution of fracture of pulpless teeth

Groups	Mode of root fracture	Number of crack/fracture propagation in roots
A	Cervical	8 Crack
	Middle	2 Fracture
	Apical	-
B	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
C	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
D	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
E	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
F	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
G	Cervical	10 Crack
	Middle	- Fracture
	Apical	-
H	Cervical	9 Crack
	Middle	- Fracture
	Apical	1

sound dentine collar<sup>32</sup>. On the other hand, a clinician can create ferrule effect when there is tooth tissue above the preparation margin with ER Post system used in this study in the clinical situation. Loading was applied directly onto the core, as no crown was used in accordance with previous studies, for simplification purposes and to exaggerate the load effect on the tooth<sup>33</sup>. However, this might have affected the stress distribution within the tooth and thus the magnitude of fracture loads and the fracture modes of the specimens. In addition, a tin foil was placed on the palatal surface of the core to standardize the surface that load applied.

Any material used as a composite buildup should be radiopaque, highly filled with glass filler for strength, pigmented to demonstrate the extent of the core and easy to use<sup>7</sup>. Hybrid type composite has both great strength and can be finished sufficiently. In view of the increasing popularity of composite resin BIS-core composite was used to build up the core in this study. It is highly filled, dual cured and has been developed especially for core

build-ups. Composite material used for core build-up was not light-polymerized in this study, because the polymerization contraction stress resulting from the light polymerization. Feilzer et al<sup>34</sup> have shown a reduced stress generation for self-cure versus light-cure composites. The polymerization shrinkage of resin-based composites under confined conditions generates stress at the tooth/restoration interface, which may lead to gap formation and poor adaptation.

Polymerization reaction of an autopolymerizing acrylic resin is an exothermic reaction. In the embedding process of specimens into the autopolymerizing acrylic resin, specimens were removed from the resin blocks after the first signs of the polymerization. Thus, effect of heat of polymerization in dentine was eliminated. The heat generated may lead to decreased moisture content, crazing, and weakening of the sample, which will indirectly affect the fracture resistance value<sup>10</sup>. It has been attempted to simulate the periodontal ligament by use of a low viscosity silicone impression material<sup>22,23</sup>. On the other hand, it was reported that the benefits of using such materials are questionable since the elasticity is different from that of the periodontal membrane and the elastic nature of the alveolar bone is not taken into account. The elastic modulus of silicone impression material used to simulate the periodontal ligament has a modulus that is much higher than periodontal ligament and the force was absorbed by the tooth tissue primarily, which may have resulted in a lower failure load than would be seen in vivo.

In this study, the teeth were loaded palatally at 135 degrees to the long axis. This angle reflects the positions, contacts and loading characteristics of maxillary central incisors in Class I occlusion<sup>35</sup>. Additionally, all specimens in this study were subjected to 5000 thermal cycling representing an aging of the bonding approximately 6 months in vivo function<sup>36</sup>. This ageing technique induces stress to the post-and-core material, cement, and the interface between dentine, cement and post-and-core. Stress between cement and post resulting in loss of adhesion increase the risk of root fracture<sup>37</sup>.

Several in vitro studies tested the fracture resistance of titanium post<sup>31,38,39</sup>. According to the results of those studies titanium posts exhibited greater fracture loads than ordinary chewing force of adults ranges from 70 to 150 N<sup>40</sup> and they were commonly used in clinical practice. Therefore, titanium post groups were used as control groups in this study.

Previous studies revealed that most clinical failures have initiated from the cementation or internal surfaces<sup>41,42</sup>. Therefore, the integrity of the luting cement to restoration

surfaces plays a major role in the longevity of the restoration and the failures originated from cementation surfaces identified the need for a reliable conditioning method to strengthen this critical area. Recent several in vitro studies evaluated the effect of tribochemical silica-coating on bond strength of composite luting cement to zirconia ceramic, glass FRC and titanium<sup>16,18-20</sup>. It was concluded that bond strength between composite luting cement and zirconia, glass FRC and titanium was increased with the use of tribochemical silica-coating. In this respect, an improvement of bonding strength between post-and-core unit and dentine should result in higher fracture resistance of the whole system. Application of CoJet before the cementation decreased the fracture resistance of glass FRC post/composite core. In an in vitro study, it was found that CoJet treatment of glass FRC posts decreased the retention of them in the root canal<sup>16</sup>. The lower the retention and adaptation of posts in the root canal, the lower fracture resistance of endodontically treated teeth<sup>43</sup>.

While application of CoJet for zirconia ceramic post/ceramic core did not affect the fracture resistance of endodontically treated teeth, however, decreased the fracture resistance of zirconia ceramic post/composite core. In addition, in no CoJet applied groups zirconia ceramic post/composite core resisted higher fracture load than zirconia ceramic post/ceramic core. This result in accordance with that of an in vitro study<sup>39</sup>.

In comparison of the post material, titanium posts with composite cores showed highest fracture resistance. This result was compatible with several in vitro studies<sup>38,39</sup>. Glass FRC posts demonstrate the lowest fracture resistance value. This may be due to flexibility of glass FRC posts. This causes stress direction toward the core or the post-tooth interface and thus decreases their success rates<sup>44</sup>. Assuming that a material providing a higher elasticity modulus (titanium and zirconia ceramic) might act as a more effective inner root canal splint than more flexible glass FRC posts in order to withstand shear forces, increased load values for titanium and zirconia ceramic should be probable.

In this study, all of the zirconia ceramic posts were fractured while none of glass FRC and titanium posts were fractured. Therefore, it should be taken into consideration that removing process of a zirconia ceramic post from root canal is almost impossible when it fractures. In that clinical situation it is indicated to extract such a tooth. This is the main disadvantage of a zirconia ceramic post.

## CONCLUSIONS

Within the limitations of this in vitro study, the application of tribochemical silica coating to the post surface (for glass FRC post/composite core and zirconia ceramic post/composite core) decreased the fracture resistance of endodontically treated teeth. Titanium post with composite core exhibited the highest fracture resistance. However they can influence negatively the aesthetics of all-ceramic crowns.

## MANUFACTURERS' DETAILS

- CoJet system, 3M ESPE, Seefeld, Germany
- CoJet Sand, 3M ESPE
- ESPE Sil, 3M ESPE
- Absolute Digimate Calipers, Mitutoyo, Sussex, UK
- EXAKT Apparatebau, Norderstedt, Germany
- Roeko, Langenau, Germany
- VDW, Munich, Germany
- AH Plus, Denstply, Konstanz, Germany
- Komet ER post kit, Komet-Brasseler, Lemgo, Germany
- Cerapost, Komet-Brasseler
- Pattern Resin LC, GC Germany, Munich, Germany
- IPS Empress Investment, Ivoclar Vivadent, Shaan, Liechtenstein
- Empress-Cosmo, Ivoclar Vivadent
- RelyX Unicem Aplicap, 3M ESPE
- RONDOflex 2013, KaVo, Biberach, Germany
- RotoMix, 3M ESPE
- Rebuilda DC, Voco, Cuxhaven, Germany
- Solobond Plus, Voco
- Dentinpost, Komet-Brasseler
- Titanpost, Komet-Brasseler
- Meliodent, Bayer Dental, Newbury, UK
- Affinis, Coltene Whaledent, Altstätten, Switzerland
- Shimadzu AG-50 kNG, Shimadzu Co., Kyoto, Japan
- SPSS/PC+, Version 15.0, SPSS Inc., Chicago

## ADDRESS FOR CORRESPONDENCE

Dr. Muhittin Toman, Department of Prosthetic Dentistry, Faculty of Dentistry, Ege University, 35100, Bornova-İzmir, Turkey. E-mail: tomantr@yahoo.com

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