

Comparison of the Fracture Resistance of Endodontically Treated Maxillary Incisors Restored with Six Different Post and Core Systems

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Abstract

Background and Aim: Different methods and materials are available for post and core (P&C) fabrication. We aimed to compare the fracture resistance and failure modes of endodontically treated maxillary central incisors restored with six different P&C systems.

Materials and Methods: In this in-vitro study, after endodontic treatment and coronal preparation of 60 maxillary central incisors, six different P&C systems were used: 1) cast base metal P&C, 2) cast gold alloy P&C, 3) zirconia post and casting ceramic core, 4) zirconia post and composite core, 5) titanium post and composite core, and 6) fiber post and composite core. Thermocycling (5-55°C, 60 seconds, 1500 cycles) was performed after cementing the full metal crowns on each tooth. A 130° force was applied at a crosshead speed of 1.5 mm/minute in a universal testing machine. The fracture force (N) and fracture patterns were recorded. Data were statistically analyzed by using Kruskal-Wallis, Mann-U-Whitney, and Fisher's exact tests ($\alpha=0.05$).

Results: The highest mean fracture resistance was recorded in the first group (904±302.77 N) followed by the third group (725±202.11 N), second group (723±224.15 N), fourth group (675±358.64 N), fifth group (424±156.85 N), and sixth group (416.5±81.58 N). The groups with casting P&Cs and zirconia post and casting core showed significant differences with the other two groups with non-casting cores ($P<0.001$).

Conclusion: The highest fracture resistance was recorded for cast metal P&C, which may be due to a better stress distribution. Zirconia post and ceramic core may be a proper and aesthetically appealing substitute for cast metal P&C.

Key Words: Composite Resins, Endodontically-Treated Tooth, Post Techniques

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Introduction

Restoration of endodontically treated teeth (ETT) is necessary for restoring aesthetics and function and preserving the remaining tooth structure [1]. As a consequence of root canal therapy (RCT), the

water content of the tooth is decreased, leading to an increased brittleness, and as a result, the fracture strength of the tooth declines by 69% [2,3].

Due to structural defects caused by caries, trauma, or previous restorations, many ETT need

reconstruction by post and core (P&C) in order to become reasonably functional. The main reason for the use of a post in these teeth is to create a mechanical retention for the core; however, this can lead to an increased risk of tooth fractures [4]. Nonetheless, the type of restoration is chosen based on the remaining tooth structure. P&C treatment is not necessary when the loss of tooth structure is minimal [4].

In general, P&C systems can be divided into two categories: casting and prefabricated P&C. Prefabricated posts can be made of metal or tooth-colored materials [3].

Cast metal P&C systems are widely used due to their favorable physical properties, high strength, and good retention. Cast gold P&Cs are considered the gold standard because of a high success rate. However, failure to achieve the desired aesthetics is a major problem encountered upon using cast metal systems [5,6].

The use of tooth-colored posts, such as ceramic posts and fiber-reinforced composite (FRC) posts, is common because of better aesthetic results. Furthermore, ceramic posts demonstrate a high strength and hardness, while fiberglass posts show a lower strength and a higher elasticity [7]. FRC posts have a higher flexural strength than metal P&Cs and zirconia posts. The modulus of elasticity (E) of these posts is close to that of dentin; therefore, they have the ability to create a single-unit bonding with the tooth [8], and they absorb most of the stress, leading to a limited stress distribution in the remaining tooth structure [7].

The use of zirconia posts with cosmetic restorations in ETT provides satisfactory results. These posts have favorable mechanical properties; however, there is a risk of root fracture due to a high modulus of elasticity (E) [9]. Placing posts with heterogeneous modulus of elasticity may cause stress concentration in the dentin and at the post-dentin interface leading to root fracture [10].

Several studies have compared the fracture strength of the teeth reconstructed with prefabricated or casting P&Cs; however, the results are contradictory [11]. In some studies, it has been concluded that the teeth restored with fiber posts have a lower fracture strength in comparison with those restored by using metal posts [12]. In other studies, the fracture resistance

of the teeth restored with fiber posts was evaluated to be equal to or more than that of the teeth restored with metal posts [13,14].

In respect to the fracture pattern, some studies have shown that the fractures in the teeth restored with fiber posts are more favorable than those in the teeth reconstructed by metal posts [15,16], while other studies have rendered contradictory results in this respect [17,18].

To date, few studies have evaluated the fracture resistance of the teeth restored by the use of cast base metal P&Cs [19]. Moreover, a limited number of studies exists with regard to the simultaneous evaluation of the fracture resistance and fracture patterns of more than four different P&C systems [20]. Therefore, there is a need for further studies to determine the most beneficial P&C system. The purpose of this in-vitro study was to determine and compare the fracture resistance and fracture patterns of endodontically treated maxillary central incisors restored with different P&C systems. The null hypothesis of this study was that there are no significant differences among the fracture resistance values of different types of P&C systems.

Materials and Methods

In this in-vitro study, 60 maxillary central incisors were extracted from 30-50-year-old patients due to periodontal diseases and were placed immediately in 5% thymol solution. Teeth with cracks, caries, or fractured restorations were excluded. Afterwards, a digital caliper (Mitutoyo Absolute 500-197-20, Aurora, IL, USA) was used to measure the diameter and height of the teeth, and the teeth with an average length beyond 23 ± 1 mm or less than 12 mm (from the cement enamel junction (CEJ) of the buccal surface to the apex) were excluded.

With 10 samples per group, there was an 80% likelihood of a significant difference among the groups in terms of the mean fracture resistance ($n=48$, $\alpha=0.05$).

After preparing access cavities, the root canals were prepared according to the passive step-back technique up to #60 K-file (Dentsply/Maillefer, Ballaigues, Switzerland). Root canal obturation was performed according to the cold lateral condensation technique by using gutta-percha

points (Aria Dent, Asia Chemi Teb Co, Tehran, Iran) and AH26 endodontic sealer (Caulk/Dentsply, Milford, DE, USA). After filling the access cavities with a provisional restorative material (GC Cavition; GC Dental Products Corp., Tokyo, Japan), the teeth were stored at 37°C and 100% humidity for a week. Afterwards, the coronal part of each tooth was cut perpendicular to the long axis and at 1 mm coronal to the mesial CEJ by using diamond discs (Ref. 070, D&Z, Berlin, Germany) mounted on a dental lathe machine (KaVo Polishing Unit, EWL 80, Leutkirch, Germany) at a low speed under constant water irrigation.

By using a long flat-end water-cooled fissure bur mounted on a high-speed handpiece, a finish line with a width of 1.2 mm was created in all the teeth. One- and 2-mm ferrule widths were formed on the proximal and the buccal and lingual walls, respectively, with approximately 6 degrees of wall convergence. A 3-degree tapered diamond bur was used to create this convergence angle similar to the method used in previous studies [21,22]. The samples were randomly divided into six groups (n=10).

In the first group, 11 mm of gutta-percha from each root canal was removed by #2-3 Peeso reamers. The root canals were prepared by using the black drill of the CosmoPost ceramic post system kit (Empress Cosmo Ingot, Ivoclar Vivadent, Liechtenstein, Germany) with the same length. A root canal impression was made by using a pattern resin (Duralay, Reliance Dental Mfg. Co, Alsip, USA), and the core was formed according to the standard preparation of a maxillary central incisor so that the height of the resin core at the buccal aspect was 4 mm above the tooth preparation. A silicone index (Panasil®, Kettenbach GmbH & Co. KG, Escheburg, Germany) was made from the formed core in order to restore the other teeth. Afterwards, the posts were invested and cast by using a base metal alloy (Supercast, Thermabond Alloy MFG, Los Angeles, CA, USA). All the P&Cs were cemented by the use of Panavia F2.0 resin cement (Kuraray Noritake Dental Inc., Osaka, Japan).

In the second group, the preparation and molding were performed in the same way as in the first

group, except that a gold alloy (BEGO, Bremen, Germany) was used for casting.

In the third group, the teeth were prepared in the same way as in the previous groups; zirconia posts of the CosmoPost system with a diameter of 1.7 mm were tested in the root canal of each tooth. The posts were placed inside the root canal of each tooth, and the core was formed by wax (Dentsply DeTrey, Surrey, England). After investing and wax removal, glass ceramics reinforced with a special Lucite system (IPS Empress® Cosmo Ingot C, Ivoclar Vivadent, Liechtenstein, Germany) were pressed into the molds. Afterwards, ceramic P&Cs were air-abraded by 50-µm aluminum oxide particles and were luted by the use of Panavia F2.0 resin cement.

In the fourth group, the teeth preparation and selection of zirconia posts were done in the same way as in the previous groups. Afterwards, the posts were cut at 3 mm above the buccal preparation by using a diamond bur (Meisinger, Dusseldorf, Germany) mounted on a water-cooled high-speed handpiece. The posts were air-abraded by 50-µm aluminum oxide particles and were luted by Panavia F2.0 resin cement. Next, the cores were built up by using a core build-up composite resin (Clearfil Photo Core, Kuraray Noritake Dental Inc., Tokyo, Japan) according to the manufacturer's recommendations.

In the fifth group, the teeth were prepared according to the method described above. The Svenska titanium post (No. L6, Svenska Dentorama, Sweden) was used for reconstruction.

To ensure the compliance of the end of these posts with the form of the root canals prepared by the #1.7 tapered-end drill of the CosmoPost system, the end of the posts were milled to achieve the same tapered shape. The posts were air-abraded by 50-µm aluminum oxide particles and were luted by Panavia F2.0 resin cement. The composite cores were reconstructed in the same way as in the fourth group.

In the sixth group, 11 mm of gutta-percha from each root canal was removed by #2-3 Peeso reamers. The root canals were prepared by using the black drill of the Anthogyr fiber post system (Fibio®, Anthogyr, Sallanches, France) with the same length. The fiber posts were cut at 3 mm

above the buccal preparations by using a diamond bur (Meisinger, Dusseldorf, Germany) mounted on a high-speed water-cooled handpiece. The posts were air-abraded by 50- μ m aluminum oxide particles and were luted by Panavia F2.0 resin cement. Next, the teeth were etched by using 35% phosphoric acid gel (Pegasus, Astek Innovations, England). The composite cores were reconstructed in the same way as in the fourth group.

At this stage, after correcting the teeth preparations, impressions were made from the samples in the six groups by an addition-curing silicone impression material (Panasil®; Kettenbach GmbH & Co. KG, Escheburg, Germany).

After die preparation, a pattern with the contour of a maxillary central incisor was formed on one of the samples by using a blue inlay wax (Kerr Co., Orange, CA, USA). A silicon index was prepared according to this pattern and was used for the contouring of the other samples. Next, investing and casting were performed, and full metal crowns were made for all the samples.

After polishing and adjusting each crown on the teeth, the crowns were cemented by using a resin-modified glass ionomer cement (GC Fuji Plus, GC Co., Tokyo, Japan) under a gentle pressure.

Each tooth was placed in a cylindrical custom-made mold and was surrounded by a self-curing transparent acrylic resin (Acropars, Marlic Medical Instruments CO., Tehran, Iran) at an angle of 130° relative to the direction of force exertion.

In order to mount the samples, each sample was attached vertically to the blade of a surveyor at the middle of the incisal edge by the use of sticky wax (Kerr Co., Berlin, Germany). The surveyor blade was brought down so that the CEJ of the tooth was sunken into the acrylic resin.

The roots were covered with a layer of wax (Dentsply DeTrey, Surrey, England), from 2mm below the CEJ to the apex, to simulate the periodontal ligament (PDL) of natural teeth. The remaining surfaces of the roots were covered with a 0.1-mm-thick thin foil. The samples were removed during the warm acrylic phase, the foil around the roots was removed, and the root space was filled with Impregum™ (3M ESPE, Seefeld,

Germany). The samples were then put back into place quickly.

In the next phase, thermocycling (1500 cycles) was performed at 60-second intervals and at the temperature of 5-55°C in a water bath. Each sample was placed in the cylindrical custom-made mold. A 130° force was applied at a crosshead speed of 1.5 mm/minute in a universal testing machine (TLCLO, Dartec Ltd., Stourbridge, England) by a round-end stainless steel pin to a point 3 mm below the incisal edge on the palatal area of the crown. The fracture force (N) and fracture patterns were recorded for each sample.

The samples with a fracture in the upper one-third of the root were considered as restorable, while the fractures at the lower two-thirds were considered as unrestorable. The results were statistically analyzed according to Kruskal-Wallis, Mann-U-Whitney, and Fisher's exact tests in SPSS software program (Version 16.0, IBM Co., Chicago, IL, USA) at a significance level of 0.05.

Results

The maximum mean fracture load was detected in the first group (the teeth restored with cast base metal alloy P&Cs), while the minimum mean fracture load was observed in the sixth group (the teeth restored with fiber posts and composite cores) (Table 1).

Because the groups did not meet the assumption of homogeneity of variances (Kruskal-Wallis test, $P < 0.001$), the relationship between the studied groups regarding the fracture resistance was evaluated by Mann-U-Whitney test (Table 2). This table shows that the groups with casting P&Cs (groups 1 and 2) and group 3 (zirconia post and casting core) have significant differences with the other two groups (groups 5 and 6) restored by non-casting cores.

The obtained results with regard to the fracture pattern in the studied groups are shown in Table 3. The Fisher's exact test revealed that there were no significant statistical differences among the studied groups in terms of the relative frequency of the fracture patterns ($P = 0.998$).

Discussion

In the present study, the fracture strength and

Table 1. Mean, standard deviation (SD), and minimum/maximum fracture load (N)

Group	Number of samples	Mean	SD	Minimum	Maximum
1. Cast base metal P&C	10	904	302.77	450	1290
2. Cast gold P&C	10	723	224.15	480	1150
3. Zirconia post and casting ceramic core	10	725	202.11	460	1000
4. Zirconia post and composite core	10	657	358.64	260	1350
5. Titanium post and composite core	10	424	156.85	300	710
6. Fiber post and composite core	10	416.5	81.58	300	540

SD=Standard Deviation, P&C=Post and Core

Table 2. Significant differences among the studied groups according to Mann-U-Whitney test ($\alpha=0.05$)

Group	2. Cast gold P&C	3. Zirconia post and casting ceramic core	4. Zirconia post and composite core	5. Titanium post and composite core	6. Fiber post and composite core
1. Cast base metal P&C	0.212	0.240	0.096	0.001	0.001
2. Cast gold P&C		0.940	0.496	0.003	0.001
3. Zirconia post and casting ceramic core			0.325	0.003	0.001
4. Zirconia post and composite core				0.185	0.173
5. Titanium post and composite core					0.472

P&C=Post and Core

Table 3. Frequency distribution (%) of fracture modes in the studied groups

Fracture mode	Cast base metal P&C	Cast gold P&C	Zirconia post and casting ceramic core	Zirconia post and composite core	Titanium post and composite core	Fiber post and composite core
Restorable	40	40	30	40	50	40
Unrestorable	60	60	70	60	50	60

P&C=Post and Core

fracture patterns of endodontically treated maxillary central incisors reconstructed by six various types of P&C systems were evaluated.

According to the results of the current study, the null hypothesis was rejected. Regardless of the limitations of this study, the findings showed the superiority of the mean fracture strength of maxillary central incisors reconstructed by cast P&C and zirconia post and casting core (Table 2). These findings concur with those of other studies which stated that a higher rigidity of posts might lead to a better stress distribution and a higher fracture resistance [23]. Similarly, the teeth reconstructed by cast metal P&Cs were reported to have a higher fracture strength [19]. This could be due to the fact that cast P&Cs exhibit a better adjustment with root canal walls, leading to a more uniform stress distribution [14]. On the contrary, a higher fracture strength was reported in the teeth constructed by the use of fiber posts in comparison with metal posts [13]. This could be associated with the close modulus of elasticity of fiber post and dentin [6,8].

According to the findings of the present study, the teeth restored by zirconia post and casting ceramic core system showed a significantly higher fracture resistance when compared to other aesthetic post systems and titanium posts (Table 2). These findings were in agreement with those reported by Heydecke et al [9]. In addition, Butz et al [24] described that the fracture strength of the teeth restored by zirconia post and composite core was significantly lower than that of the teeth reconstructed by zirconia post and ceramic core. Therefore, it is suggested that zirconia posts and ceramic cores can be used as an alternative to cast P&Cs in the frontal aesthetic zone, as was recommended previously [9].

In addition, Heydecke et al [9] reported a higher fracture strength for zirconia post and composite core compared to titanium post and composite core system; we also found similar results. However, no significant differences were found in the two studies in this regard. These findings were in contrast to the results of the study by Toksavul et al [25]. Although zirconia post and composite core seem to be beneficial when early restoration is needed in the aesthetic zone, a major disadvantage

of such ceramic posts is the difficulty of removal from the root canal [26].

The lowest fracture strength was found in the group of teeth reconstructed by means of fiber post and composite core system. The fracture strength was significantly lower in this group in comparison with groups 1, 2, and 3, as was the case in some other studies [19]. The low fracture strength of the teeth restored by fiber posts could be due to the low modulus of elasticity (E) of such posts, which leads to an increased bending of the P&C unit under loading; consequently, more stress is exerted on the tooth [2]. On the other hand, in some studies, the lower modulus of elasticity (E) of fiber posts was considered favorable, and the teeth restored by fiber posts demonstrated a higher fracture strength compared to metal posts [8,13].

It is worth mentioning that although the mean fracture strength of fiber posts (416.5 N) was found to be poor in our study, it was higher than the value reported in other studies (200 N) [26-28]. Thus, it could be concluded that these posts are resistant to regular occlusal forces.

In the present study, there was no significant difference among the groups in terms of the fracture type. Nevertheless, the greatest numbers of unrepairable fractures were seen in the group restored by zirconia post and cast ceramic core system. Such findings are in accordance with the results of a study by Akkayan and Gulmez [26]. It was declared that because of the high modulus of elasticity (E) of zirconia posts, forces are transferred to the tooth-post interface [29], leading to severe tooth fractures [26]. However, the findings of Toksavul et al [25] were in contrast to the mentioned finding as they stated that the teeth reconstructed by zirconia post and cast ceramic core showed the lowest frequency of unrepairable fractures. In addition, Heydecke et al [9] found fewer unrepairable fractures when using zirconia posts.

In the present study, we tried to choose the natural teeth with a close age range. In addition, the teeth with similar lengths and widths were selected and were randomly divided into six groups to decrease the effect of various tooth diameters. One of the disadvantages of extracted natural teeth is that even if they have similar diameters, they may

differ in terms of the contour, dentin thickness, moisture content, and shape of root canals; these factors could influence the stress distribution in the remaining tooth structure [30]. On the other hand, the use of plastic teeth does not simulate the modulus of elasticity (E) and bonding characteristics of natural teeth [25]. In addition, Strub et al [31] reported the higher fracture strength of natural teeth compared to artificial teeth.

The environment in which the teeth are kept influences the changes in hard dental tissues, particularly in dentin [32]. In previous studies, either normal saline or thymol solution was utilized [33]. It was described that normal saline could negatively affect the bond strength between the post and dentin [34]. Hence, we used thymol solution for tooth preservation. The teeth were collected within the last six months, as suggested by Naumann et al [33].

In some studies, gutta-percha and sealers were not used as they might decrease the adhesion of the cement to dentin [35]. Although the application of eugenol-based sealers can affect the properties and bonding of resin cements, root canal obturation itself has little effect on the root strength [36]. Moreover, by eliminating gutta-percha and sealer, the real clinical setting cannot be replicated, and the results could not be translated to in-vivo situations [33]. Therefore, in the current study, the root canals were obturated by using gutta-percha points and AH26 endodontic sealer.

A great number of studies up until 2009 evaluated the fracture strength of the teeth restored without placement of veneers [37]. Although this method eliminates the effect of some variables including the quality, contour, and thickness of the veneer, it does not simulate the clinical practice repercussions. Moreover, the impact of ferrule on the final treatment outcome cannot be determined [33]. In the current work, full metal veneers were applied in order to reinforce the teeth. However, such veneers are not used in the frontal aesthetic zone, and their fracture characteristics might be different from those of porcelain-fused-to-metal or full ceramic veneers [33].

Various appropriate ferrule widths have been reported in the literature [9,25]. In the present study, this width was set at 2 mm in buccal and

lingual areas, and at 1 mm in the proximal area, similar to previous studies [9,25].

We subjected the teeth to a static load applied to the palatal aspect of the crown at a 130° angle. Such an angle can simulate the forces applied to maxillary central incisors in an Angle class I dentition [25]. However, simultaneous application of dynamic and static loads may reproduce a more realistic oral condition [9].

In order to simulate the clinical settings, the physiological mobility of teeth should be reproduced [33]. In the present study, the PDL was imitated by using a thin layer of Impregum™ to simulate physiological tooth movements. Materials such as polyether, silicone, polyvinyl siloxane, and artificial PDL have been used in previous studies [33].

Acrylic polymerization is a heat-releasing process. The removal of the experimental teeth during the primary stages of polymerization, as performed in the current study, may prevent damages to dental structures that would indirectly affect the fracture strength [38]. However, materials such as plaster or acrylic resin [39] could not accurately mimic the characteristics of maxillary or mandibular bones, and the influences of such materials on the outcomes of previous studies should be considered [33].

Conclusion

In the present laboratory study, the highest fracture strength was detected in the teeth restored by cast metal P&Cs compared to the other evaluated systems, which might be due to a better stress distribution pattern. The lowest fracture resistance was found in the teeth restored by fiber post and composite core. Zirconia post and ceramic core may be a proper and aesthetically appealing substitute for cast metal P&C.

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