Fracture resistance and failure pattern of endodontically-treated maxillary premolars restored with fiber-reinforced and cast posts and cores.

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Abstract:

Objectives: The aim of this study was to compare the fracture resistance and failure modes of endodontically treated maxillary premolars restored by either a glass fiber-reinforced composite post system or a cast gold post and core and restored with all-ceramic crowns.

Materials and Methods: Forty extracted maxillary premolars were selected. After endodontic treatment, the specimens were randomly distributed in two groups (n= 20) and restored with either glass-fiber posts or cast gold post and core, followed by an IPS Empress II crown. Teeth were submitted to loading, after which resistance to fracture was measured. Fracture patterns were observed after ink suffusion.

Results: Fracture tests revealed no significant difference in fracture resistance. However, the correlation between the type of post and the type of failure (restorable/non-restorable) was found to be highly significant (Pearson chi-square test, $p<0.001$).

Conclusions: Within the limits of this study, cast post and cores caused significantly more unrestorable fractures than their fiber reinforced counterparts.

Key words: fracture resistance, failure patterns, post and core, endodontically treated teeth.

Introduction

As a result of continuing improvements in the predictability and prognosis of endodontic treatment, the need for the restoration of the coronal structures of such teeth is likely to increase.[1-3] It is also likely that the need to restore endodontically-treated teeth will increase as more people retain teeth into older age.[4-6] Most endodontically-treated teeth are structurally compromised by virtue of the peripheral destruction that led to the need for endodontic treatment initially, as well as the central destruction that was necessitated by the endodontic treatment itself.

The primary purpose of a post is to provide retention for the core when most of, or all the clinical crown has been destroyed. Consequently the inherent retention and stability of the post and core system are crucial for the success of the final restoration.[7-10] Variables such as post length, diameter, geometric design, surface configuration, and cement type, are some of the mechanical factors that affect the retention and stability of posts.[3,9,11] With regard to the physical properties of the material from which the post is fabricated, compatibility of its resiliency with that of the surrounding remaining root structure are important factors in the stability and fatigue resistance of the restored tooth. The long-term outcome of such a restoration is thus likely to be affected by the interaction of all these variables.[12, 13]

Regarding the stability of cemented restorations, it is known that the geometric features of the preparation are important in the resistance to the dislodgement of restorations by functional stresses.[14] The distribution and transmission of such stresses within the restoration-tooth complex, and the luting cement in particular, play a vital role in the long-term stability of the restoration. Loss of resistance, brought about by excessive

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stresses or poor geometric form, is a progressive rather than an uncompromising phenomenon, and has been linked to fracture and dissolution of luting cement, leakage, plaque retention, and secondary caries.[15]

The quality of the marginal fit of crowns and fixed partial denture (FPD) retainers is generally regarded as an important requirement for successful treatment.[16] Marginal deficiencies in excess of 50 μm have been linked to secondary caries formation,[17] which is regarded as the most common cause of failure of crowns and fixed partial denture retainers.[18-20] Endodontically-treated teeth with crowns and fixed partial denture retainers exhibit inferior longer-term clinical outcomes compared to vital teeth,[17] and it may be speculated whether the inherent weakness of such teeth due to their compromised structural state puts them at greater risk for fatigue failure. The risk of coronal leakage for an unsuccessful endodontic outcome is already recognized, with studies showing that even apparently adequate endodontic fillings may not be effective against such leakage.[21,22]

From the foregoing, it is apparent that, with respect to the restored endodontically-treated tooth, a number of issues arise. It is clear that the issue of resiliency and its relationship with leakage and fatigue failure is likely to be closely linked with some of the physical properties of the post. With the growing availability and popularity of newer non-metallic posts, which have quite different physical properties from those of metals, there is a need to know more about their behavior under functional loading.

The aim of this study was to compare the fracture resistance and failure modes of endodontically treated maxillary premolars restored by either a glass fiber-reinforced composite post system or a cast post and core and restored with all-ceramic crowns. The null hypothesis tested was that these variables were not influenced by the type of post and core used.

Materials and methods

Tooth selection and endodontic procedures

Forty freshly extracted, single-rooted maxillary premolars, free from caries or previous restorations, were selected for the study. The specimens were cleaned of external debris, examined by trans-illumination for the presence of cracks, and stored in an incubator at 37°C at 90% relative humidity, prior to the commencement of mechanical testing. Initial probing was accomplished using #10 K-files (Flexofiles, Maillefer, Ballaigues, Switzerland) and RC Prep (Premier Dental Products Company, King of Prussia, PA, USA). Root canal length was established through direct observation of the file extruding from the foramen. Root canals were then prepared using nickel titanium rotary instrumentation (25mm ProTaper, Maillefer) in crown-down fashion according to the following sequence: SX, S1, S2, F1, F2, and F3 to root canal length. Irrigation was performed with 5.25% sodium hypochlorite (Clorox, Clorox Co, Oakland, CA, USA). Preparation was considered complete when the root canal accepted the insertion of a medium size master-cone (Maxima, Henry Schein Inc., Melville, NY, USA) 1mm short of full root canal length. Root canal obturation was carried out using Pulp Canal Sealer EWT (Kerr, Romulus, MI, USA) as sealer and the System B (Analytic Endodontics, Redmond, OR, USA) technique as described by Buchanan.[23] The coronal part of the canal was backfilled using Obtura II (Obtura Corp, Fenton, MI).

Preparation of the specimens

Each tooth was embedded in a block of self-curing acrylic resin (Jet Kit, Lang Dental Manufacturing Co., Wheeling, IL) with the long axis perpendicular to the base of the block and with the acrylic ending at 2 mm below the cemento-enamel junction (CEJ). Prior to embedding, a thin layer of glycerine was first applied with a microbrush on the roots and the teeth were carefully removed after polymerization of the acrylic resin. An addition-polymerization polyvinylsiloxane (Flexitime, Heraeus-Kulzer, Hanau, Germany) was injected into the acrylic resin molds and the tooth was re-inserted to simulate the periodontal ligament. The teeth were randomly distributed into two groups (n=20) (Table 1). The crown margins were prepared using MRD gauged diamond points (Lot-NR 1599, DFS Dental and Technical Products, GmbH, Germany), which were attached to the hand piece of the milling machine. The MRD gauged diamond had a self-limiting tip which produced a deep chamfer of a uniform width of 1mm. In this manner, the crown margins and the angle of convergence were standardized. The gingival margin was placed 1mm above the CEJ for all the forty specimens. After the gingival margin preparation, the coronal dentinal was cut to obtain 2mm of ferrule length in both groups.

Restorative procedures

For Group 1, gutta-percha was removed with a Largo drill No. 1 (Dentsply-Maillefer) to a depth of 7 mm, keeping at least 5 mm of root filling intact to preserve the apical seal. A post-space was prepared with calibrating drills and 17% EDTA was used to clean the root canal. Translucent glass-fiber posts #1 (FRC Postec, Ivoclar-Vivadent, Schaan, Liechtenstein) were used. Each post was cut to adequate length with a diamond bur so that the post extruded 2mm above the ferrule height for each of the two groups.

Post cementation was carried out with self-cured resin cement (Multilink, Ivoclar Vivadent) following manufacturer's instructions. A silane coupling agent (Monobond-S, Ivoclar-Vivadent) was applied on the post surfaces for 60s and then air-dried. Core build-up was performed using hybrid composite resin (Tetric Ceram, Ivoclar-Vivadent) which was applied in increments of 1mm and light polymerized (Astralis 10; Ivocar-Vivadent) for 40s until the core was restored to predetermined dimensions. The final layer was placed using a transparent matrix to allow for shape consistency between samples.

For Group 2, the post space was prepared as in Group 1 to a depth of 7 mm, keeping at least 5 mm of root filling intact to preserve the apical seal. The post-space walls was prepared with the same calibrating drill of Group 1 and 17% EDTA was used to clean the root canal. A cast metallic post and core was fabricated from a direct wax pattern. The core portion shape was carved to match the transparent mold used to make the resin cores in Group 1. The pattern was then cast using type 3 gold alloy (Midas, Jelenko-Heraeus Kulzer, Armone, NY, USA).

Cementation procedure was identical for both groups using self-polymerized resin cement (Multilink, Ivoclar-Vivadent). A single-stage impression was later made using polyvinylsiloxane impression material (Virtual, Ivoclar-Vivadent) and master dies were fabricated with type 4 die stone (Jad Stone, Whip Mix, Louisville, KY). The IPS Empress II ingots were pressed and the frameworks were then layered with IPS Empress II ceramic using a template for shape consistency between specimens. Cementation of the crowns was performed using the same resin cement. Crowns were pretreated with hydrofluoric acid (IPS ceramic etching gel, Ivoclar-Vivadent) for 20s, rinsed off, air dried, and silanized with Monobond-S for 60s and air dried. Multilink primer liquids were mixed and applied on the whole tooth surface for 15s. Resin cement was dispensed from the automix syringe directly into the inner surface of the crowns. The restorations were seated and held in position under a load of 20 N; excess resin was removed immediately with a micro-brush. In all groups, restoration margins were covered with glycerine gel after removal of excess and rinsed off after complete polymerization of the resin cement. The specimens were finally stored in distilled water at 37°C for 24h before they were used for static fracture resistance measurement.

Fracture resistance test

Fracture tests were conducted using a universal loading machine (Instron 8500 Plus, Instron, 100 Royal St. Canton USA). Each specimen was inserted into the holding device and a controlled load was applied using a stainless steel rod with a 2mm tip-diameter in a direction parallel to the longitudinal axis of the tooth at a crosshead speed of 1mm/min. Load was applied in the middle of the occlusal fossa as to simulate an occlusal load. All specimens were loaded until fracture and the maximum breaking loads were recorded in Newtons (N). After mechanical failure, all fractured specimens were perfused with blue ink to highlight the fracture lines. The failure mode was visually evaluated and classified as restorable (no fracture or horizontal fracture of the root) or non-restorable (oblique or vertical fracture of the root extending more than 3mm below the cervical line). Restorable specimens were inspected for microcracks using a stereomicroscope (Zeiss OpMi1, Zeiss, Oberkochen, Germany) at 10x magnification. The Mann-Whitney rank sum test was used to compare fracture resistance

Table 1: Means and standard deviations of the fracture loads obtained for all groups. Similar letters indicate no significance ($P > 0.05$).

Group	Type of post	Number of specimens	Mean ± SD (N)
I	Fiber reinforced post and composite core	20	500.32 ± 16.18 ^{A}
II	Cast post and core	20	491.58 ± 38.25 ^{A}

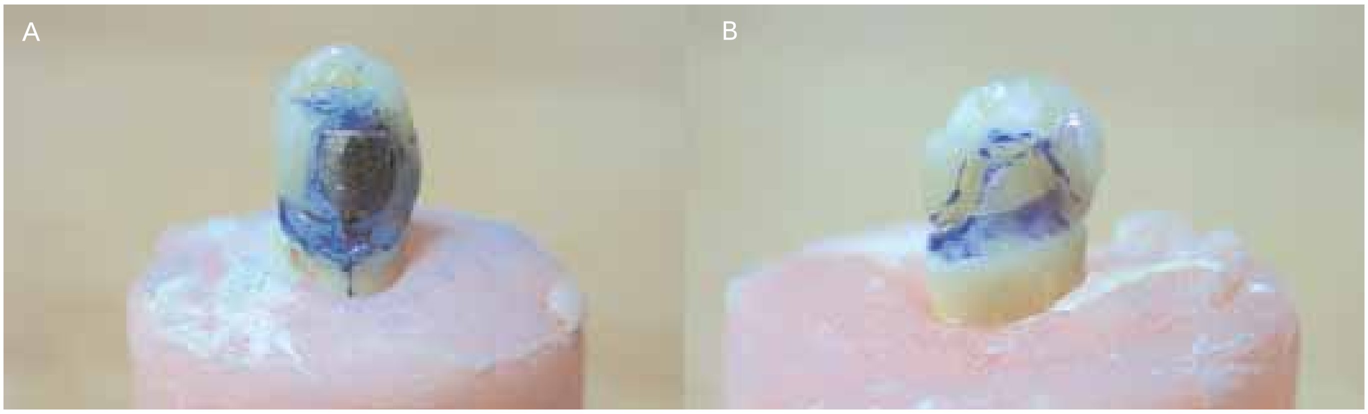

Figure 1: A: Example of unrestorable fractures linked to the used of cast post and core. B: Type of the restorable fractures obtained following the use of fiber-reinforced posts.

and Pearson's chi square test was used to compare restorability. The level of significance was set at $\alpha = 0.05$.

Results

Although the data passed the Kolmogorov-Smirnov normality test, it failed the Levene's test of normality showing the standard deviations to be significantly different, and thus the Mann-Whitney rank sum test was used (SPSS 12) which indicated no significant difference in fracture resistance between the tested groups (Table 1). However, the difference between the groups with regards to the type of failure ($P<0.001$) was found to be highly significant; more restorable fracture for Group 1 (Figure 1A and 1B) and more non-restorable fracture for Group 2 (Figure 2).

Discussion

Although this study was designed to compare the fracture resistance and failure pattern of endodontically treated maxillary premolars restored with a full-ceramic crown using either a cast gold post and core, or a fiber-reinforced post and a composite core, several factors were considered to represent clinical failure. A layer of resilient silicon was used to simulate the periodontium as its presence was found to significantly affect fracture testing results[24]. Furthermore, as preparation and cementation procedures are critical for all-ceramic restorations[25], a surveyor was used to ensure similarity of all core shapes. An epoxy resin-based endodontic root canal sealer was chosen to avoid the possible detrimental influence of eugenol-containing sealers on adhesion between root dentin, luting agents and fiber posts. In the conditions of the present experimentation, we have to accept the null hypothesis tested regarding fracture resistance as there was no difference between the two groups. However, the null hypothesis had to be rejected regarding fracture patterns as there was a significant difference between cast post and core restorations and fiber-reinforced post with composite core restorations.

Under vertical loading conditions, fracture loads of specimens restored with cast posts were comparable to those with fiber-posts, which is in accordance with previous studies[26-28]. Accordingly, it cannot be assumed that fiber-posts significantly offered extra advantages with regard to the reinforcement and strengthening of the endodontically treated teeth. It has also to be noted that this study investigated only the influence of vertical compression stresses. As Hayashi et al.[29] reported different results with oblique loading conditions, further research should to be performed under other clinically relevant loading conditions.

It has also been reported that the ordinary chewing force of adults ranges between 7 to 15 kg, and the maximum biting force could reach up to 90 kg[30]. As the fracture loads in all groups in the present study were found to be greater than the ordinary chewing force, and even greater than the maximum biting force, their mechanical strength could be considered satisfactory from a clinical point of view [31,32].

In terms of the failure modes, the obtained results were in accordance with previous studies[29,33], showing that the application of fiber posts to endodontically treated teeth produces more favorable fracture patterns, which could be clinically managed without sacrificing the restored teeth. It could be assumed that specimens restored with fiber-reinforced post systems offered more homogenous stress distribution as reported in recent finite element analysis studies[36-39]. Such studies have revealed that when a fiber post possessing a similar modulus of elasticity to that of dentin is used, better stress distribution occurs at the post/dentin interface[34-37]. This could explain why all fractures in the fiber post group were limited to the cervical portion of the root including the core-dentin interface, since the stresses were concentrated in the cervical area and the outer root surface.

The major clinical advantage is that such type of fracture is amendable to repair[38]. It has to be noted however that this study followed a "continuous static load to fracture" pattern. Clinically, restorations are subjected to cyclic loading during function creating the possibility for fatigue to initiate and/or

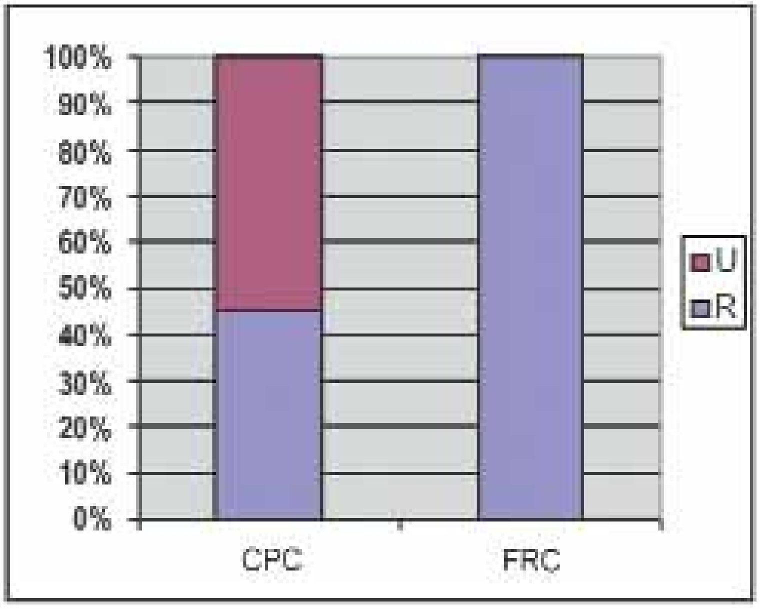

Figure 2: The relationship between the type of posts in endodontically treated teeth and the type of tooth fracture exhibited after vertical loading stresses is displayed in this figure. In presence of a fiber post, the frequency of restorable fractures is significantly higher (FRC: fiber post and composite core system; CPC: cast post and core system).

exacerbate low-level damage that otherwise would not cause failure[39]. During function, the restoration-luting cement-tooth complex is subjected to variable loading and unloading patterns separated by different relaxation periods. In addition, the loading environment also plays a role, as a new type of fracture pattern was recently observed (inner cone cracks specific to glass and ceramic loaded in wet conditions was reported) [39]. Further research is needed to account for cyclic loading and thermomechanical cycling in non-axial loading that was described in previous studies as responsible for clinical failure due to fatigue rather than static loading [40-41].

Acknowledgement

This study was supported by the College of Dentistry Research Center of King Saud University in Riyadh, KSA (Grant No F1109).

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