Original Article

Fracture resistance of endodontically treated maxillary premolars restored with lithium disilicate restorations using three different retentive techniques

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Abstract

To compare fracture resistance of endodontically treated maxillary premolars restored with ceramic restorations using three retentive techniques. Forty maxillary premolars were randomly selected as a control (Group 1), composite core/crown (Group 2), fiber-reinforced composite post/composite core/crown (Group 3) and endocrown (Group 4). All restorations were thermo-cycled and subjected to vertical loading. Fracture load and fracture modes were analyzed. The results showed that Group 3 recorded a significantly highest fracture load (2304 ± 737 N). Pairwise comparisons showed no significant difference between Group 2 (1229 ± 303 N) and group 4 (1609 ± 395 N). Type of coronal-radicular retention was significantly associated with fracture mode ($p = 0.002$). All fractures in Group 4 were non-restorable. After adjusting for fracture load (limited to Groups 1-3), logistic regression displayed no significant differences in fracture mode between Groups 1, 2 and 3. In conclusion, the all-ceramic crowns presented the highest fracture strength when fiber-reinforced composite posts and composite cores were included in the restoration of endodontically treated maxillary premolar.

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Keywords: endocrown, fiber-reinforced composite post, fracture mode, fracture resistance maxillary premolars

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Introduction

Dentists have long recognized the differences between vital and non-vital teeth. The clinical perception is that following endodontic treatment teeth become more fragile and do not serve as well as vital teeth. However, there are experimental studies revealed that endodontically treated teeth are not more fragile than teeth with vital pulps (Lewinstein and Grajower, 1981, Sedgley and Messer, 1992) Weakness or brittleness of non-vital teeth are attributed to the loss of tooth structure following caries, trauma, and consequent dental treatment rather than changes in the dentin (Reeh et al., 1989, Panitvisai and Messer, 1995). Additionally, there is an evidence that pulpless teeth lose a protective feedback mechanism, which may increase risk of tooth fracture (Randow and Glantz, 1986).

Restoration of endodontically treated teeth remains a challenge in restorative dentistry. Full coverage indirect restorations have been reported to increase survival rate of endodontically treated posterior teeth compared with directly placed restorations (Salehrabi and Rotstein, 2004, Stavropoulou and Koidis, 2007). The traditional approach for restoring such teeth is the use of a core a crown. If the remaining tooth structure is inadequate for retention of a core, a post may be required (Schwartz and Robbins, 2004). In endodontically treated molars, the pulp chamber and canal extensions usually provide sufficient retention for a core buildup (Nayyar et al., 1980). Posts are generally considered necessary for premolars due to their relatively small pulp chambers (Cheung, 2005). However, a study by Krecji *et al.,* suggested that adhesive techniques may obviate the need for posts in endodontically treated premolars (Krejci et al., 2003). Fokkinga *et al.,* also found no differences in fracture resistance and failure modes between endodontically treated maxillary premolars restored with and without posts (Fokkinga et al., 2005). Clinical and laboratory studies have demonstrated that post space preparation and the metal post itself may weaken the tooth and make the root more vulnerable to fracture. Within the last forty years, several authors have reported that metal posts do not reinforce endodontically treated teeth. (Sorensen and Martinoff, 1984, Trope et al., 1985, Morgano, 1996). However, with the advent of fiber posts and adhesive luting techniques, some authors have described a reinforcement effect from luting fiber posts into the root canals with adhesive materials (D'Arcangelo et al., 2010, Goncalves et al., 2006, Hayashi et al., 2006). The risk of failure through root fracture may be reduced by preparing an adequate cervical ferrule (Creugers et al., 2005, Naumann et al., 2018). Different ferrule lengths have been investigated and recommended. While some authors suggested a 1 mm ferrule (Ma et al., 2009), others advocated a 1.5 to 2 mm ferrule (Libman and Nicholls, 1995).

For decades, cast posts and cores or prefabricated metal posts and cores were regarded as the treatment of choice for endodontically treated teeth. Although these metal posts have an acceptable long-term survival rate (Balkenhol et al., 2007, Raedel et al., 2015), they are not without disadvantages. The elastic modulus of such posts is substantially higher than dentin which can cause unfavorable stress distribution and increase the risk of root fracture. Metal posts may shine through translucent all-ceramic restorations or cause grayish appearance of the marginal gingiva. In recent years, prefabricated fiber-reinforced composite posts have been developed and gained popularity over traditional metal posts in anchoring cores and crowns to the roots. The main reasons for this change are the need for tooth-colored posts, posts with elastic modulus similar to dentin and the potential to bond these posts to the root. When fiber-reinforced composite posts are used, according to reports, most have survival rates similar to metal posts (Sterzenbach et al., 2012, Sarkis-Onofre et al., 2014, Cloet et al., 2017). However, metal posts are associated with more unfavorable complications, i.e., root fracture (Jung et al., 2007, Salvi et al., 2007). Failures of fiber-reinforced composite posts are mainly post debonding or post fracture (Ferrari et al., 2007, Cagidiaco et al., 2008). which can be resolved through reintervention. Although failure of fiber-reinforced composite posts is less likely to cause root fracture, time of service after recementation is a concern and post removal may further weaken the root.

Removal of dentin during post space preparation weakens the tooth root and add a risk of accidental root perforation. Besides, abnormal root anatomy, such as severe root curvature or short roots, may preclude post placement. An alternative restoration design that combined esthetics and the benefit of covering the cusps is an adhesive crown that utilized the prepared pulp chamber for macro-and micro-mechanical retention (Pissis, 1995). This type of restoration, known as endocrown (Bindl and Mormann, 1999), can be fabricated from different CAD/CAM materials, e.g., feldspathic ceramic, glass-ceramic, and polymer-infiltrated ceramic. Endocrowns are relatively new compared with the intraradicular post and core systems. Their clinical studies are scarce and most reports have short follow-up periods and contain small sample sizes (Bindl and Mormann, 1999, Otto, 2004, Bindl et al., 2005, Decerle et al., 2014, Otto and Mormann, 2015). These investigations revealed more endocrown failure when adhesively bonded to premolars than molars. It is, therefore, suggested that endocrown is should be used for molars only and indicated for extensively damage molar (Bindl et al., 2005, Otto and Mormann, 2015). Nevertheless, a few in vitro evaluations suggested that the use of endocrown is possible for premolars (Lin et al., 2010, Lin et al., 2011, Guo et al., 2016). Yet none of these studies included core without post in their experiments. The authors believe that if the pulp chamber is sufficient to retain endocrown, it should be also sufficient for core build-up. Therefore, the present *in vitro* study was designed to compare the fracture resistance and fracture mode of endodontically treated maxillary premolars restored using lithium disilicate crowns cemented on composite cores in the absence and presence of fiber-reinforced composite posts, and endocrowns. The null hypothesis was that there is no difference in the fracture resistance among these experimental groups.

Materials and Methods

This study was carried out under approval of the Ethical Committee of Thammasat University, Thailand. Forty sound human maxillary first premolars of similar dimensions (bucco-lingual width 8.25 ± 0.5 mm, mesio-distal width 5 ± 0.5 mm and root length 15 ± 1 mm) were selected base on these inclusion criteria: caries-free, no visible fracture line, almost straight root and completely form apices. All the teeth were cleaned and stored in a solution saturated with thymol. Ten teeth were kept as controls, i.e. their crowns were not removed (group 1). The remaining 30 teeth were subjected to endodontic treatment and filled with gutta-percha using Grossman's sealer and lateral condensation technique. Each of the tooth crowns was sectioned 2.5 mm above the CEJ using a diamond saw under water lubrication. Preparation of the remaining coronal part consists of a 1-mm wide circumferential chamfer margin located 1.0 mm above the CEJ to produce a 1.5 mm ferrule. The teeth were randomly distributed into 3 groups (n = 10) according to the following restorative protocols (Figure 1A): the pulp chamber-retained core and full crown group (group 2), the intraradicular post-retained core and full crown group (group 3), and the endocrown group (group 4).

Post cementation/buildups for Group 2 and 3 were made using a dual-curing single component total-etch adhesive (Excite F DSC, LOT T18878, Ivoclar Vivadent AG, Schaan, Liechtenstein) and a dual-curing composite core build-up material (MultiCore Flow, LOT

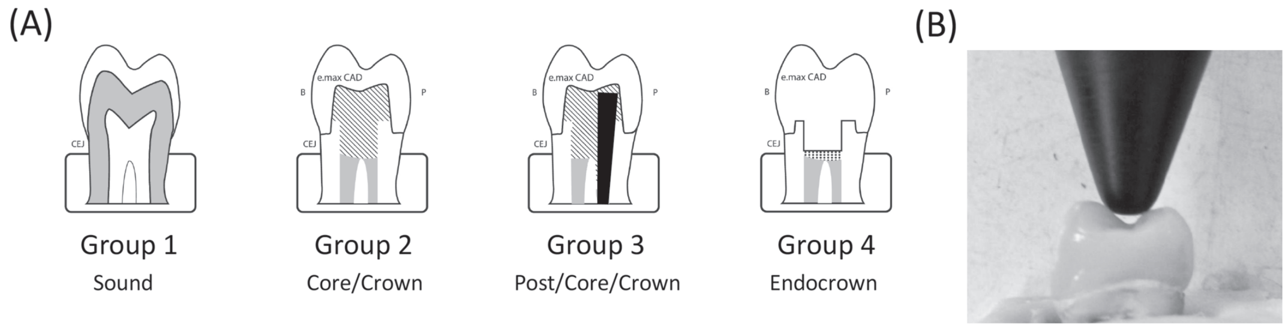

Figure 1: Schematic representation of the preparation (A) and applied loading direction (B).

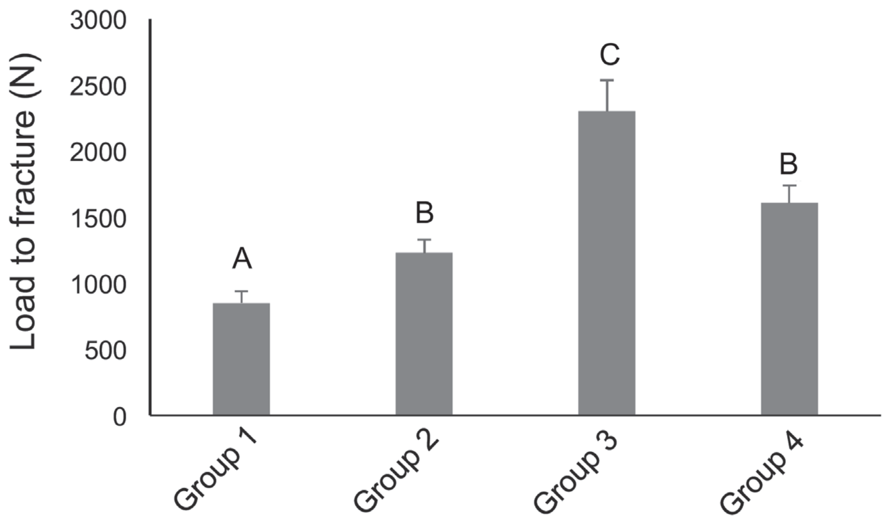

Figure 2: Mean fracture strength of endodontically treated premolars with different corono-radicular restoration. The values are expressed as average loads (N) to fracture +/-SE (n=10). Groups with the same alphabet are not statistically significant different ($p>0.05$).

V13048, Ivoclar Vivadent AG, Schaan, Liechtenstein). The base of the pulp chamber in Group 2 was lined with 1 mm-thick flowable restorative material (Beautifil Flow, LOT T071307 Shofu, Kyoto, Japan). The pulp chamber and periphery were etched and bonded as per manufacturer's instructions, the core material was injected into the pulp chamber and the core build-up using matrix and light-cured for 10 seconds. Roots of Group 3 received fiber-reinforced composite posts (D.T. Light-Post Illusion X-RO, LOT 319571607, RTD Dental, France) and composite cores in which the gutta-percha was removed from the palatal canal to 10 mm measured from the preparation margins. The post space was prepared with the D.T. Drills for a post size of 1. The post was tried-in, cut 3 mm above the remaining tooth structure and cemented using a dual-curing single component total-etch adhesive and a dual-curing composite core build-up material. The core material was carried into the post space with an intracanal tip. The post was placed into position, excess material was spread to cover the occlusal preparation and light-cured for 20 seconds. The filling core was injected into the matrix wrapped around the prepared tooth and light-cured for 10 seconds.

Preparations of Group 4 were confined within the pulp chamber to eliminate undercut areas and aligned pupal walls with internal taper of 8 to 10 degrees. The floor of the pulp chamber was lined with flowable restorative material up to 4 mm below the prepared margin. Each of the tooth in groups 2 and 3 was taken for refining the preparation to a height of 4 mm and the total occlusal convergence angle of 20 degrees.

Samples in Group 2 to Group 4 were successively positioned into a custom-made upper dental model containing recess located at the first premolar site with the preparation margins of all specimens at the same level and secured with plasticine. Digital impressions were made with a chairside intraoral scanner (Cerec Omnicam, Sirona Dental Systems, GmbH, Bensheim, Gemany). A full dentate antagonist model was also scanned and held against the working model for digital occlusal registration. Crowns and endocrowns were automatically designed by the Cerec AC CAD/CAM software (SW 4.4) using the Biogeneric individual design mode. Specimens from each restoration design were milled from a 14-size lithium disilicate glass-ceramic (IPS e.max CAD, LOT V21789, Ivoclar Vivadent AG, Schaan, Liechtenstein) followed by crystallization and glazed following the manufacturer's protocol. The finish restorations were adjusted and seated on the preparations using silicone fit-test material (Tokuso FIT TESTER, Tokuyama Dental, Japan).

All crowns/endocrowns were cemented using a dual-curing/light-curing luting composite (Variolink N, LOT V11158, Ivoclar Vivadent AG, Schaan, Liechtenstein) and a light-cured multi-component adhesive system in Variolink N kit (Syntac, Ivoclar Vivadent AG, Schaan, Liechtenstein). Prior to cementation of the restorations, the experimental teeth were embedded in auto-polymerizing acrylic resin (Instant Tray Mix, Lang Dental, USA) up to 1 mm below the CEJ. The fitting surface of the milled restoration was etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, LOT V12791, Ivoclar Vivadent AG, Schaan, Liechtenstein) for 20 seconds, thoroughly rinsed with water spray, and dried with oil-free compressed air. A silane coupling agent (Monobond Plus, Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to the etched surface with a microbrush for 60 seconds and dispersed the excess with compressed air.

The tooth surface was prepared for cementation by cleaning with pumice slurry, followed by 30 seconds of 37% phosphoric acid (N-Etch, LOT U54981, Ivoclar Vivadent AG, Schaan, Liechtenstein) etching to clean the surface and etched the enamel areas. Etchant gel was washed with vigorous water spray and excess water removed according to the wet-bonding technique. The etched surface was conditioned (Syntac Primer) for 15 seconds and gently air dried, primed (Syntac Adhesive) 10 seconds and gently air dried, bonded (Heliobond) air thinned but not light cured. A dual-curing/light curing luting composite was mixed and applied on the prepared inner surface of the restoration and seated on the tooth. Following elimination of excess unpolymerized luting composite, all margins were covered with an air-blocking barrier (Liquid Strip) and light cured for 20 seconds per surface.

After thermocycled for 5,000 cycles from 5°C to 55°C water baths with a 5 seconds dwell time, the specimens were mounted on an Instron testing machine and loaded in compression along the long axis of the tooth. The load was applied with a steel ball contacted the inner slopes of buccal and lingual cusps with a crosshead speed 0.5 mm/min until failure (Figure 1B). The maximum breaking loads were recorded in Newton (N). The failure mode was determined based on 2-examiner agreement as restorable if the fractures were above the CEJ no more than 1 mm below the CEJ (which in a clinical situation would require surgical crown lengthening or orthodontic

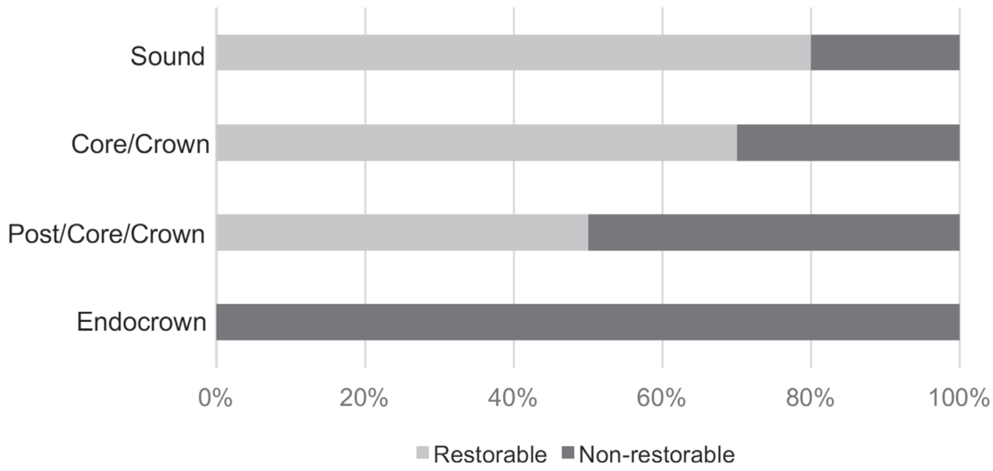

Figure 3: Summarized fracture pattern, comparing percentage of restorable and non-restorable samples.

extrusion) and non-restorable if the fractures were more than 1 mm below the CFJ (which in a clinical situation would require tooth extraction).

Fracture resistance of premolar teeth between the groups were compared using the one-way ANOVA followed by post-hoc Bonferroni test at the significant level of 0.05. Fracture modes of the groups were analyzed with Chi-square test and logistic regression.

Results

The results of mean maximum fracture load of the experimental groups are shown in Figure 2. For maximum fracture loads, group 3 (2304 ± 737N) was significantly higher than the rests, while group 2 (1229 ± 303N) and 4 (1609 ± 395N) were not statistically different. Intact teeth (group 1) recorded the lowest fracture load (850 ± 279N).

Frequency of the fracture modes in the 4 groups is shown in Figure 3. In the untreated group, 20% of the specimens showed non-restorable failure characteristic, while group 2 and 3 displayed 30% and 50% respectively. The fracture modes: restorable and non-restorable shown in Figure 4A and 4B. Chi-square analysis showed that type of coronal-radicular retention significantly influenced fracture mode (p = 0.002). Only in group 4 were all fractures rated as catastrophic failures and therefore, excluded from the logistic regression. After adjusting for fracture load, samples in groups 2 and 3 were 1.3 and 1.5 times more likely to exhibit non-restorable fracture compared with the control group. However, this association was statistically non-significant.

Discussion

A design concept commonly applied to crowns cemented on core or post-core foundation is ferrule, while design feature of the standard endocrown is a circumferential butt margin without ferrule. There is, however, an *in vitro* study suggested the benefit of ferrule on fracture resistance of endocrown in molars (Einhorn et al., 2017). The present study incorporated ferrule into the endocrown for this reason.

The null hypothesis of this study was rejected. Fracture resistance of lithium disilicate crowns supported by fiber-reinforced composite posts and composite cores was significantly higher than those supported by composite cores and endocrowns. The greater fracture resistance gained from fiber-reinforced composite post and composite core could indicate the advantage bonding the post to root canal dentin. In the current study, the samples were thermocycled 5,000 cycles for the following reasons. It has been shown

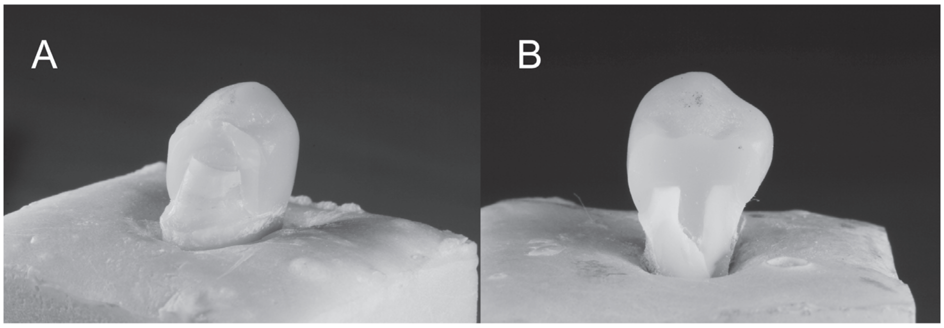

Figure 4: Schematic representation of the fracture mode, A: restorable and B: non-restorable.

that 500 thermocycles, as suggested by the ISO standard, did not significantly affect the bond strength of composite resin to dentin surfaces (Nikaido et al., 2002) and that of 5,000 cycles were effective in the degradation of the composite resins (Özcan et al., 2007, Rinastiti et al., 2011). In this experiment, resin composite core material was used to adhesively bond fiber-reinforced composite post to the root canal instead of resin cement for 2 reasons. Apart from having modulus of elasticity close to that of dentin, the core buildup resins have been shown to significantly increase bond strengths to the root canal compared with traditional resin cements (Aleisa et al., 2013). Combination of the above-mentioned conditions could allow the system to better distribute stress throughout the remaining tooth structure and thus the highest failure load. This finding differs from earlier results which reported that endocrowns are equivalent to classical crowns in term of facture resistance (Lin et al., 2010, Lin et al., 2011, Guo et al., 2016). The causes of this disparities could be from differences in the research designs. The subjects in two of these investigations were maxillary premolars restored with endocrowns and conventional ceramic crowns made with feldspar ceramic blocks (Vita Mark II, Vita Zahnfabrik). In addition, one of the two employed axial fatigue-load prior to static load-to-failure test while the other used only static load. The third one contained mandibular premolars with the final restorations made from lithium disilicate ceramic blocks (e.max CAD, Ivoclar Vivadent) and the load was applied 45° to the long axis of the tooth. It should be noted that endocrowns in these studies contained no ferrule while conventional crowns had a 1.5 mm ferrule. The results of our study raise the question whether ferrule enhances fracture resistance of endocrown in premolar as found in molar. Our study also showed that fracture resistance of endocrowns were higher than crowns supported by composite cores but not statistical significance. These two retention techniques provide similar bonding surface area which is less than the post and core method.

The fracture mode may be considered in the selection of coronal-radicular retentive methods. All the teeth restored with endocrown recorded as non-restorable because the restorations and teeth experienced mesio-distal vertical fracture which split into two pieces with only one adhesive failure. This finding agrees with in vitro studies that have reported the majority of or all endocrowns experienced catastrophic failure (Biacchi and Basting, 2012, Einhorn et al., 2017). The core without post group in this study had similar fracture resistance to that of the endocrown group but majority (70%) of the former recorded higher favorable failure mode. In addition, half of the post core group exhibited restorable fracture. We may, therefore concluded that endocrown does not benefit in protecting endodontically treated maxillary premolars from fracture. The result of this study was different from that of Fokkinga et. al (2005) who reported that root filled maxillary premolars restored with composite cores and complete crowns have similar fracture resistance to those with posts, while our study found that fiber-reinforced composite posts and composite cores have greater fracture resistance. This disparity could be explained from differences in crown materials used (ceramic versus composite), adhesive bonding schemes (etch-and-rinse versus self-etch), loading angle (parallel versus 30° with the long-axis of the tooth), crosshead speed of testing machine (0.5 mm/min versus 5 mm/min).

Adequate root canal treatment and coronal restoration significantly affect clinical success of endodontically treated teeth (Gillen et al., 2011). Many studies have focused on determining the most suitable post and core and crown system. Although certain beneficial effect of the post is, in general, believed to be desirable and required, this remains inconclusive in the literature. It has been proposed that sufficient ferrule lessens the influence of the post and core system (Juloski et al., 2012). The results from the present study demonstrated the added value of the radicular post placement, as shown by a statistically significant increase in fracture resistance of the fiber post/core/crown group compared with the other tested groups without radicular post extension (Figure 2). It is possible that in our study using premolars, radicular fiber post may help distribute stress, from the applied occlusal load, to surrounding root dentine and surrounding structures. This also decreases stress concentration within the tooth structure, which is particularly important in premolar teeth, where the lateral occlusal forces are applied, and the amount of remaining tooth structure is limited. This hypothesis is supported by previous studies (Bessone and Fernandez, 2010, Kumar and Rao, 2015, Upadhyaya et al., 2016). Moreover, our unpublished preliminary data obtained from a finite element analysis suggest that under occlusal force loading, a radicular fiber post reduces certain stress in enamel and dentin layers by approximately 5-35%, further supporting the additional role of the fiber post, apart from its key role in retaining the coronal core. The behavior of fiber posts has also been suggested to be similar to that of natural teeth, resulting in uniform stress distribution over the system (Bessone and Fernandez, 2010). Whether or not this is likely to be applied for the restoration using metal cast post system needs further studies. Both experimental *in vitro* studies and finite element analyses are undoubtedly beneficial to examine this.

Another aspect that deserves discussion is the use of natural teeth as a control group. The goal of endodontics and restorative dentistry is to restore mutilated endodontically treated teeth so that the tooth/restoration complex can function as long as the natural teeth. Surprisingly, the fracture load of the control group in this study was significantly lower than those of the experimental groups. Values for fracture resistance of maxillary premolars found in other studies ranged between 882 N to 1568 N. (Soares et al., 2008). This variance may result from many factors. Dental hard tissues are gradient and anisotropic while restorative materials are homogeneous and isotropic. Jaw movements are multi-directional and dynamic while experimental loading is static, unidirectional and high above natural biting force. Nonetheless, static loading can be considered acceptable for comparison between restorative techniques and materials (Taha et al., 2014).

A limitation of this study was that the failure loading protocol did not incorporate load cycles at physiological loads preceding static load to fracture that would more closely mimic conditions in the oral cavity. Future study should include different coronal-radicular retentive techniques with and without ferrule and using fatigue protocol.

Conclusion

Within the limitation of this study, the following conclusion can be drawn:

1. Fiber-reinforced composite post and composite core has superior fracture resistance compared with composite core and endocrown in endodontically treated maxillary premolar.

2. Composite core or fiber-reinforced composite post and composite core protected the remaining tooth structure better than endocrown in endodontically treated maxillary premolar.

3. Restoration of endodontically treated maxillary premolars with endocrowns are not recommended.

Conflict of interest

The authors declare that they have no conflicts of interest regarding this study.

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