Original Article

Fracture Resistance of Endodontically Treated Premolars with Deep Cervical Lesions Restored with and without Posts in Different Restorations

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Abstract

The purpose of this study was to evaluate the effects of fiber posts and different restorations on the fracture resistance of endodontically treated maxillary premolars with cervical cavities. In forty extracted human first maxillary premolars, cervical cavities were prepared simulating cervical lesions and randomly divided into four groups (n=10): COM-NP, endodontically treated teeth (ETT) restored with resin composite without fiber posts; ON-NP, ETT restored with CAD/CAM ceramic onlays without fiber posts; COM-P, ETT restored with resin composite and fiber posts; and CR-P, ETT restored with CAD/CAM ceramic crowns and fiber posts. After the fiber posts and restorations had been cemented with resin cement, all specimens were loaded onto the long axis in a universal testing machine until fracture at a speed of 0.5 mm/min. Fracture load (N) and fracture modes were evaluated in all specimens. The mode of failure was determined by visual inspection. Data were analyzed with Welch's ANOVA and Games-Howell tests ($p<0.05$). Fracture load for all groups were (N): COM-NP (933.48±242.53); ON-NP (1871.45±313.59); COM-P (1510.17±251.87); and CR-P (2189.97±600.38). COM-NP had the lowest fracture resistance, significantly different from those of the other groups ($p\leq0.05$). Statistically significant differences were observed among groups ($p\leq0.05$), except in the ON-NP to CR-P groups ($p=0.471$). All groups showed the non-restorable fracture mode. Cuspal-coverage restorations significantly enhanced the fracture resistance of endodontically treated maxillary premolars with cervical cavities. Placement of fiber posts improved the fracture resistance of endodontically treated teeth but did not make the failure restorable.

Keywords: Fracture load, onlay, CAD/CAM, fiber post

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Introduction

Endodontically treated teeth (ETT) are usually characterized by essential coronal and radicular tooth structure lost as a result of dental caries, previous restorations, and endodontic access preparation that negatively influenced tooth strength.[1,2] The primary cause of extraction among endodontically treated teeth is tooth fracture related primarily to improper prosthetic restorations.[3,4] The longevity of endodontically treated teeth depends not only on the use of conservative endodontic procedures but also on appropriate coronal restoration of the tooth.[3,5,6] The remaining tooth structure is the most effective parameter in the selection of proper restorations because it is considered significant in resisting the fracture of ETT.[7-10] The greatest preservation of remaining tooth structure showed higher fracture resistance and also increased the survival rates of endodontically treated teeth.[7,11-14] Among posterior teeth, the highest rate of clinical fractures was in maxillary premolars due to unfavorable anatomic shape, making them more susceptible to cusp fracture.[15,16] In addition to the tooth structure lost during endodontic treatment, non-carious wedge-shaped cervical lesions are another factor reported to occur significantly in premolars, further weakening tooth strength.[17-20] The association of these factors probably makes premolar teeth more susceptible to fracture.[19]

Today, different principles and materials can be used to restore endodontically treated teeth, from conservative alternative to progressive approaches. As a conservative concept for endodontic preparation restricted to endodontic access, direct composites can be used as definitive restorations to avoid further tooth preparation, which weakens tooth strength.[8,10,14,21,22] *In vitro,* a high fracture resistance of ETT restored with resin composite has been reported.[23,24]

However, as a protective concept, posterior ETT should receive a cuspal-coverage crown restoration to protect the teeth from fracture. Several studies have reported that cuspal-coverage restorations significantly improved the success rate and longevity of endodontically treated posterior teeth.[4,6,10,14] Additionally, posts are another option being used to restore ETT. Posts are normally used only to retain the core material of ETT, but they do not reinforce the root.[4] Moreover, post space preparation can damage residual tooth structure, causing the root to weaken and the mechanical resistance of treated teeth to be decreased.[21] However, several studies reported that posts increased the fracture resistance of endodontically treated teeth.[25] Fiber posts have been suggested as an alternative to metal posts because they have a modulus of elasticity similar to that of root dentin, which improves stress distribution and avoids force concentration at the post-dentin interface.[26-28] One clinical study indicated significantly greater clinical success for premolars restored with posts compared with teeth that had been restored without posts.[27] However, laboratory studies did not show significantly increased fracture resistance for molars and premolars restored with fiber posts.[12]

Although endodontically treated teeth have been extensively studied, the choice of an optimal restorative method (conservative or protective approach) and material to restore non-vital teeth remains controversial. Based on the author's literature review, there are no publications on the association between endodontically treated premolars and deep cervical lesions. Thus, the purposes of this study were to measure the different modes of restoration after endodontic procedures with deep cervical lesions to assess the resistance to fracture and fracture modes of these teeth under simulated occlusal load. The null hypotheses were that the restorations and fiber post have no effect on the fracture resistance of restored endodontically treated maxillary premolars and no effect on fracture modes.

Materials and methods

Tooth preparation and root canal filling

This study was approved by the Research Ethics Committee, Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2017-013). The study used forty human two-rooted maxillary first premolars with straight canals extracted for orthodontic reasons and stored at 37°C in a solution of 0.1 % thymol. The time from extraction to the mechanical testing of teeth was less than 6 months. Inclusion criteria were: sound teeth with a bifurcated canal at the middle third of the root; no sign of cracks, defects, and caries on visual examination under 2.8x magnifying loupes, with fully developed apices and complete root length. The average lengths of teeth used in this study were 22±1 mm, with bucco-lingual coronal dimensions of 9±1 mm and mesial-distal coronal dimensions of 7±1 mm, measured by means of a digital caliper at the labial midpoint of the cemento-enamel junction (CEJ) level. Initial preparation of the teeth involved the removal of any superficial staining, calculus, and adhering soft tissue with an ultrasonic scaler. The specimens were assigned to one of four groups (n=10) (Fig. 1) as follows: COM-NP, ETT with cervical cavity restored with resin composite without post; ON-NP, ETT with cervical cavity restored with ceramic onlay without post; COM-P, ETT with cervical cavity restored with resin composite and fiber post; and CR-P, ETT with cervical cavity restored with full-coverage crown and fiber post. Cavity preparation mimicked cervical lesions that were wedge-shaped with divergent walls located in enamel (occlusal margin) and cementum (cervical margin). The cavities were prepared by means of a cylinder diamond bur (835 023 Intensive, Grancia, Switzerland) at 45° to the buccal surface to create wedge-shaped lesions at the CEJ until a bur depth of 2.0 mm was reached as an outline forming and creating a sharp internal line angle of 90°. For standardization, post-preparation dimensions were finalized again in all specimens: 2.4 mm deep, 5 mm wide occluso-cervically, 4 mm long on the occlusal wall, and 3 mm long on the cervical wall. A periodontal probe was used to verify the depth. After cavity preparation, Optibond FL Adhesive (Kerr, Orange, CA, USA) was applied and restored the cavities with resin composite (Premise, Kerr, Orange, CA, USA). Light-curing was performed with a LED light-curing unit for 20 seconds. (DemiPlus, Kerr Corporation, Middleton, WI, USA)

An endodontic access cavity was prepared in the center of the occlusal surface with a high-speed handpiece with a round diamond bur until the root canal orifices were identified. The access opening was oval on the occlusal surface and in the middle third of the tooth. Buccal and palatal cusps were not undermined during access opening preparation. The root canal length was determined by a #10 K-Flex file (Kerr Sybron, Romulus, MI) until the tip of the file was visible at the apical foramen. Teeth with initial apical files (IAF) 20-25 were included in this study. The working length was established 1 mm short of the apex. The root canals were instrumented by means of K-Flex file and prepared up to X4 using ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) to the working length. Each file was used with a brushing motion, and a 3-mL quantity of 2.5 % NaOCl was used to irrigate at each change of instrument. Each instrument was used to enlarge eight canals only. Apical patency was performed by a No.10 K-file. Final irrigation was done by 1 mL of 17 % EDTA and 3 mL of distilled water and dried with 3 absorbent paperpoints for 3 seconds each (Dentsply, Maillefer, Ballaigues, Switzerland). After instrumentation, all canals were obturated by the lateral condensation technique with AH Plus (Dentsply, DeTrey, Konstanz, Germany). Digital x-rays confirmed the quality of canal obturation. The excess gutta percha was removed from the pulp chamber with a heated instrument, and the access cavities were wiped with alcohol. Endodontic access was etched with 37.5 % phosphoric acid for 15 seconds followed by adhesive preparation by Optibond FL and restored with resin composite (Premise) according to the manufacturer's instructions. Light-curing with a LED curing light for 20 seconds.

Post space preparation

After 3-month storage, gutta percha was removed to prepare post spaces in the COM-P and CR-P groups at the palatal canal with a Largo drill No. 1 (Largo; Dentsply Maillefer, Ballaigus, Switzerland) Post spaces were prepared with pre-shaping drills followed by D.T. drill No. 1 (D.T. Light-Post Double Taper; Bisco Inc., Schaumburg, IL, USA) to achieve a post space length with at least 4 mm of gutta percha remaining in the apical third. Syringe irrigation was performed with distilled water (3 mL in 3 minutes), then 3 absorbent paperpoints were used for 3 seconds each. The prefabricated fiber post no.1 (DT Light Post Illusion X-RO, Bisco, Schaumburg, USA) was wiped with alcohol according to the manufacturer's recommendation.

Fiber post luting procedure

Before the luting posts were placed, a digital x-ray was used to check the quality of post space preparation. Cavity and canal were etched with 37.5 % phosphoric acid 15 seconds, rinsed with water spray and dried with paper points. Subsequently, adhesive agent OptiBond Solo Plus was applied by disposable microbrush and immediately rubbed on all surfaces of root canal walls in the canal. The solvent was removed by air blown gently. The posts were prepared with the same adhesive agent and placed with a dual-cured resin cement (Panavia SA Cement Plus, Kuraray, New York, USA), seated in the root canals, and stabilized. Excess cement was removed with a brush. The cement was light-cured for 20 seconds from occlusal direction with the tip directly contact with the post. Each post was cut to an adequate length with a diamond rotary cutting instrument to cover its occlusal end with resin composite up to at least 2 mm. The resin composite (Premise) was restored followed by light-curing with a LED curing light for 20 seconds. A digital x-ray was taken to check the quality of post placement. Samples were inserted in polyvinyl chloride (PVC) mold with 18 mm internal diameter, 22 mm external diameter and 40 mm height. The molds were filled with auto polymerizing acrylic resin (Palapress; Heraeus Kulzer GmbH, Hanau, Germany). Teeth were placed 3 mm up from cementoenamel junction (CEJ). (Fig. 2)

Onlay preparation

Before the preparations, an impression of each tooth was made with a heavy-body silicone impression material (Zhermack Elite HD, Badia Polesine, Rovigo, Italy) as an anatomic guide to obtain an original form while the restoration was applied. All specimens in the ON-NP group were prepared by an initial occlusal reduction generating 2 mm of clearance for the onlay. All angles were rounded and all prepared surface were refined using fine and superfine diamond cutting instruments (Intensiv, Montagnol, Switzerland). Onlays were scanned by intraoral scanner (Cerec AC Omnicam; Sirona Dental Systems, Bensheim, Germany) and generated with the CAD/CAM system (Cerec SW v. 4.5.2; Sirona Dental Systems GmbH, Bensheim, Germany). All specimens were fitted with the anatomy of a first maxillary premolar with cusp tips parallel to the preparation surface. Teeth were scanned, and onlays were designed. On the basis of this scan, a virtual onlay with defined wall thickness was constructed. The onlays were milled with lithium disilicate (e.max CAD blocks, Ivoclar Vivadent, Schaan, Liechtenstein) and crystallized in a ceramic furnace (Programat P700, Ivoclar Vivadent) according to the crystallization/Glaze LT program. All restorations were polished mechanically by means of a commercial polishing kit (Jota All Ceramic Kit 1369, Jota AG, Rüthi SG, Switzerland). The bonded surfaces of the ceramic onlays were etched with 9.5 % HF (Porcelain etchant, Bisco, Schaumburg, IL, USA) for 90 seconds in accordance with the manufacturer's instructions. After onlays were rinsed thoroughly, Silane Primer (Kerr, Orange, CA) were applied to etched surfaces; after 1 minute, the restorations were hot-air-dried for 2 minutes. After the surface treatment and before insertion, the restoration was protected from light to prevent premature setting. Tooth preparations were treated by 30 second etching with 37.5 % phosphoric acid, then rinsed with water and dried. Restoration and tooth surfaces were coated with adhesive resin (Optibond Solo Plus) and left unpolymerized until the application of the luting material. The dual-cure resin cement system (NX3, Kerr, Orange, CA) was applied to the inner surfaces of restorations and seated on their corresponding prepared teeth with vertical seating pressure and residual cement was removed. Buccal, lingual, mesial, distal, and occlusal surfaces were light-polymerized for 20 seconds for each surface. The restored teeth were stored in distilled water at room temperature for 7 days prior to being tested.

Crown preparation

For the CR-P group, ten premolars were conventional prepared by means of round-ended tapered diamond cutting instruments D2, D8, and D16 (Intensiv, Montagnola, Switzerland) to obtain a 6-degree convergence between walls. Preparation dimensions were done according to manufacturer's instructions as follows: 1.0-1.5 mm buccal and lingual reduction, 2-mm reduction was performed on the occlusal surface and 1.0 mm-deep chamfer placed 0.5 mm occlusal to the CEJ. Crowns were fabricated with lithium disilicate (e.max CAD blocks) and cemented with NX3 resin cement. Surface treatment and tooth surface preparation were followed by method mentioned earlier.

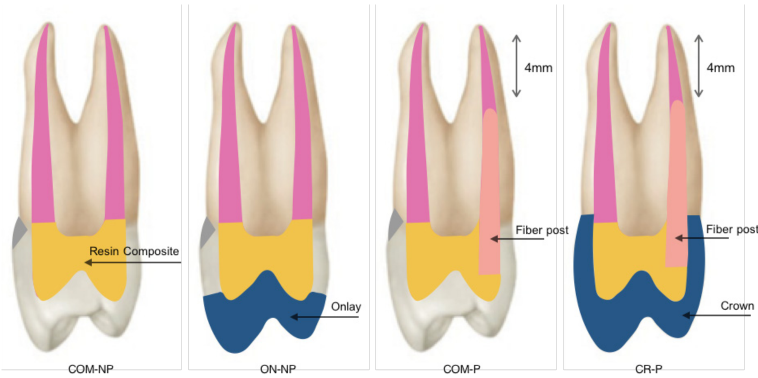

Figure 1 *COM-NP, ETT with cervical cavity restored with resin composite without post; ON-NP, ETT with cervical cavity restored with ceramic onlay without post; COM-P, ETT with cervical cavity restored with resin composite and fiber post; and CR-P, ETT with cervical cavity restored with full-coverage crown and fiber post.*

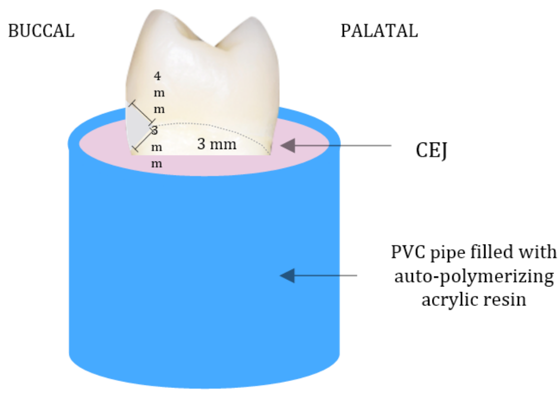

Figure 2 *Teeth were placed 3 mm up from cementoenamel junction (CEJ)*

Compressive fracture resistance testing

Specimens were tested using a universal testing machine (Instron 5566, London, UK). Each specimen was inserted perpendicular to the horizontal plane in the holding device. A controlled load was applied by means of a stainless steel tip (2-mm diameter) in a direction parallel to the longitudinal axis of the tooth. Pressure from the rod tip was applied at the central fossa contact of both buccal and lingual inclines, to simulate an occlusal load. The load was applied at a crosshead speed of 0.5 mm/minute. All samples were loaded until fracture, and the maximum breaking loads were recorded in Newtons (N). (Fig. 3) The mode of failure was recorded and classified as restorable or unrestorable. The failure mode was visually inspected, and the restorations were classified as unrestorable with the appearance of fractures located below CEJ (Fig. 4). Data of fracture load and mode of failure were collected by the author and analyzed using statistical software (IBM SPSS Statistics version 20.0). Welch's ANOVA was used to compare the mean failure load for each group. Significant ANOVA results were also tested with the Games-Howell test, with the statistical significance of $p<0.05$. Pearson chi-square test was used in this study for fracture modes with the statistical significance of $p<0.05$.

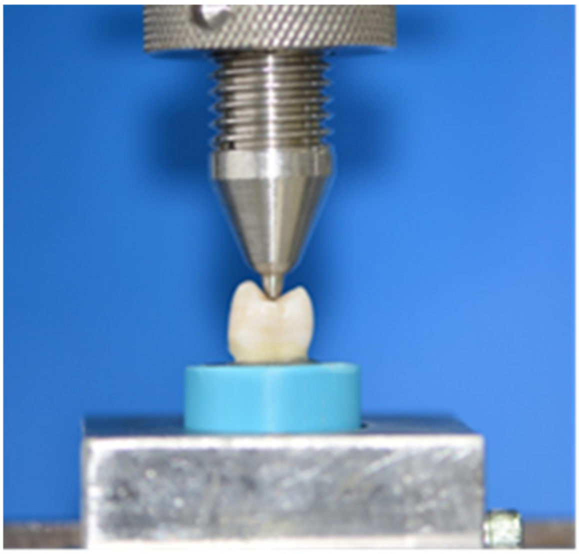

Figure 3 *specimens were tested using a universal machine*

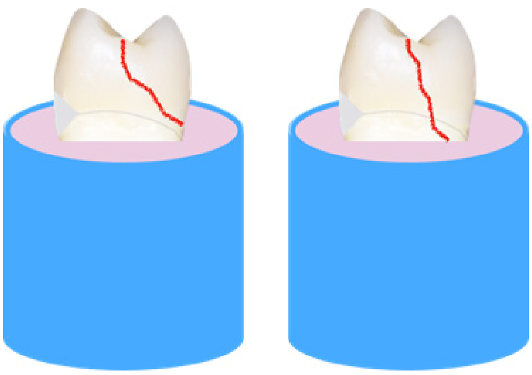

Figure 4 *Mode of failure classification*

Results

Table 1 *Mean value of fracture resistance of the tested groups (n=10)*

Group	Mean±SD (N)
COM-NP (Composite WITHOUT fiber post)	933.48±242.53[a]
ON-NP (Onlay WITHOUT fiber post)	1871.45±313.59[b]
COM-P (Composite WITH fiber post)	1510.17±251.87[c]
CR-P (Crown WITH fiber post)	2189.97±600.38[b]

Means with the same superscript letter are not significantly different from each other (p>0.05).

Table 2 *Fracture modes of the tested groups (n=10)*

Group	Restorable (%)	Non-restorable (%)	Pearson chi-square test
COM-NP (Composite WITHOUT fiber post)	0	100	A
ON-NP (Onlay WITHOUT fiber post)	0	100	A
COM-P (Composite WITH fiber post)	30	70	A
CR-P (Crown WITH fiber post)	20	80	A

Fracture modes followed by different upper case letters are significantly different at p<0.05.

The highest fracture resistance was 2189.97±600.38 N, recorded for the CR-P group, followed by 1871.45±313.59 N for the ON-NP group and 1510.17±251.87 for the COM-P group, with the lowest fracture resistance (933.48±242.53 N) recorded for the COM-NP group. Welch's ANOVA showed significant differences between COM-NP and all test groups ($p \leq 0.05$). However, there was no significant difference between the the ON-NP and CR-P groups (p=0.471). The fracture loads (mean±SD) are presented in Table 1.

The failure mode was determined by visual inspection and was classified into two major types relative to the CEJ (Table 2). Specimens that presented fracture above the CEJ were classified as restorable, whereas those that presented fracture below the CEJ were classified as non-restorable. Although most of specimens showed non-restorable mode of failure and there were no significant differences in mode of failure among all groups (p>0.05), only fiber post groups showed restorable fracture.

Discussion

This study investigated the fracture resistances of ETT with deep cervical lesions restored with fiber posts and various restorations. The mode of failure of ETT with various types of restorations was also examined. We found that cuspal-coverage restorations composed of crown and onlay showed higher fracture resistance compared with composite restorations. Based on these results, it was determined that the fiber post influences fracture strength when teeth are restored with composite restoration but does not affect the mode of failure significantly.

In this study, the fracture resistance of ETT restored with fiber posts and crowns (CR-P) did not differ significantly from that of those restored with onlay without fiber posts (ON-P). Both groups are representative of cuspal coverage restorations which are significant differences from the rest of our results. In 2002, Aquilino and Caplan stated that other forms of coronal coverage, such as gold, ceramic, or resin composite onlays, could provide RCT teeth with protection against fracture compared

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with full-coverage crowns.[6] Moreover, several studies reported that endodontically treated maxillary premolars should be restored with cuspal-coverage restorations to protect and reduce the risk of fracture.[6, 7, 10] When fractures occurred, cuspal coverage was considered to avoid vertical fracture at the cemento-enamel junction, especially when teeth were subjected to lateral forces, because fractures in cuspal coverage mostly occurred within the restorative materials.[29, 30] In 1984, Sorensen and Martinoff demonstrated that endodontically treated maxillary premolars with crowns showed significantly increased success rates of 93.9 %, whereas post-endodontic restorations without crowns showed success rates of only 56 %.[4] Also, several studies compared teeth with and without crowns and reported significant differences in longevity. Crown placement extended the average time before extraction in ETT.[3, 6, 14] Recently, a retrospective study by Suksaphar and colleagues in 2018 reported that the survival rates of premolars in relation to fracture of full-coverage crowns were higher than those of direct resin composite restorations.[10] Supporting by our results, cuspal-coverage restorations tended to achieve more desirable outcomes than direct resin composite restorations even in the group that fiber posts were inserted. This finding is consistent with the previous recommendation for post-endodontic restorations in posterior teeth. However, Ibrahim and colleagues address the opposite results saying that tooth preparation for crowns in premolars significantly decreased fracture resistance due to remaining tooth structure destruction; maximal thickness of axial tooth structure at the crown margin is necessary to resist fracture.[9]

Nevertheless, in this study, fracture resistance after restoration with crowns and onlays, considered to preserve tooth structure, showed similar results. From this point of view, onlays are superior in terms of reductions in the amount of tooth loss, especially in the cervical area. Preparation for onlays could reduce tooth loss from 67.5–72.3 % compared with conventional crown preparation of 5.5–27.2 %.[31] The greater the amount of remaining tooth structure, the more fracture resistance the ETT have.[1, 6, 7, 16, 32] In addition, supragingival location of the margin for onlays avoids periodontal irritation and gingival inflammation and makes the margin easily detected.[33, 34]

The drawback of this study was the lack of data from group restored with fiber post and onlays which would be beneficial to draw a better conclusion. However, several studies have already investigated fracture resistance and failure mode between lithium disilicate onlay restorations with and without fiber post. The results showed no significant differences were found in the groups with fiber posts in terms of fracture resistance.[35, 36] It leads to the conclusion that insertion of fiber posts did not increase the fracture resistance significantly. In latter study, the results of failure mode had significant differences among the groups which was consistent with our results.[36]

From the results of this study, the group restored with composite without fiber posts (COM-NP) showed the lowest fracture resistance. In terms of physical and mechanical properties, Soares and colleagues reported that direct composite resin restorations are inferior to ceramic restorations due to the side effects of composite polymerization shrinkage and also the process of fabrication in the laboratory of ceramics could enhance fracture resistance.[17, 37] In contrast to many studies that supported resin composite as a post-endodontic restoration for endodontically treated premolars with limited loss of tooth structure or where marginal ridges are preserved.[8, 38, 39] Also, advantages of this conservative protocol as a final restoration can reduce treatment times and costs for patients.[10] There is evidence that resin composites perform better in stress distribution under occlusal force.[40, 41] However, comparison within the composite groups, fiber post placement significantly increased the fracture resistance of direct restorations.[7, 8, 12, 25, 42] Fiber posts improved stress distribution along the adhesive interface because their elastic modulus was close to that of dentin,[26, 27] which found contradict to previously published results that showed no differences in fracture resistance after fiber post insertion.[16, 40, 41] In addition, when compared between group restored with resin composite restoration and fiber post to group restored with onlay without fiber post, the results showed the latter group exhibit higher fracture resistance. Assuming that post preparation by the removal of dentin from the canal decreases tooth strength and leads to fracture.[41] It has been recommended that posts be inserted only when insufficient tooth structure is present, with the goal of facilitating the retention of restorative materials.[4] Also, another reason for onlay group showed higher strength might come from being cuspal coverage restorations from the information stated above.

No difference was found in modes of failure among the four groups in this study, we failed to reject the second null hypothesis. Several classifications for mode of failure have been proposed either mechanical cause which is adhesive/cohesive or clinical implications which is restorable/unrestorable. In this study we observed based on the extent of fracture compared to CEJ level. Almost all specimens fractured in an unfavorable mode. Likewise, studies by Fokkinga and colleagues in 2005[43] and Forberger and Gohring in 2008[44] indicated that failure modes in post-restored groups were 90 % unrestorable and involved deep root fracture. However, the results that some restorable fracture were found only in both fiber post groups was interesting, which might imply that fiber post could somehow enhance and affect the mode of failure. Further carefully designed studies are needed to confirm this finding.

In the present study, the means of fracture resistance in all groups were higher than 100–400 N, which is the range of normal forces in normal occlusion for maxillary premolars. So the minimum threshold in the premolar area which might be capable of withstanding bite force is 400 N.[9, 45] The mean fracture load was at least more than 2 times greater than this threshold, suggesting that all restorations in this study could withstand forces during function.[46] However, this study was a static laboratory test, measuring fracture resistance that could not simulate dynamic oral conditions in many respects, such as magnitude, direction, and rate, but Sorrentino and colleagues[12] proved that static and fatigue loading conditions showed comparably high stress concentration areas and similar failure patterns.[12, 46]

Different forces have been applied to investigate mechanical resistance including compression, shear and tension respectively. However, static analyses of resistance to fracture have usually been performed with compressive tests until fractures occurred[14, 43, 47] When maxillary premolars are tested with an optimal size of stainless steel tip are considered to reproduce the mean width of antagonist teeth present in the simulated clinical situation.[12] Most static mechanical fracture tests reported in the literature are characterized by a loading of the premolars at 130°-150° to the longitudinal axis which simulates non-axial forces.[7, 43, 44] On the contrary, this study was decided to load the specimens in a direction parallel to the longitudinal axis of the tooth simulating a physiological occlusion in order to distribute the stresses more evenly between the residual dental tissues and the restorative material.[12] Load application area could vary from the center of the tooth to supporting cusps. Some studies load was applied either at the palatal cusp[12] or the buccal cusp[16] to represented parafunctional oral habits, this study investigated loads placed at the center of the tooth to simulate normal occlusion.[12, 17, 21, 42] Hannig *et al.* pointed out the importance of applying loads in unaltered areas of teeth in order to achieve reliable data and avoid the influence from tooth/restoration interface.[47]

Limitations of this study were our inability to recreate, in the laboratory, cervical lesions occurring in natural teeth, and the variations in depth in the natural process. Additional factors which might have affected the results include tooth anatomy, the lack of a simulated periodontal ligament, and the simulation of biting force from only one direction instead of the multiple directions of actual biting force. Further studies are also needed to include the use of a thermal cycling machine and the simulation of the periodontal ligament.

Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. Cuspal-coverage restorations significantly enhanced the fracture resistance of endodontically treated maxillary premolars with cervical cavities.

2. Placement of fiber posts resulted in a significant improve the fracture resistance of endodontically treated teeth with cervical lesions but did not significant make the failure restorable. However, fiber post insertion reduces 20-30% of non-restorable fracture in all specimens.

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References

1. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. ***J Endod*** 1989;11(11):512-6.
2. Alharbi FA, Nathanson D, Morgano SM, Baba NZ. Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts *in vitro*. ***Dent Traumatol*** 2014;4(4):317-25.
3. Vire DE. Failure of endodontically treated teeth: classification and evaluation. ***J Endod*** 1991;17(7):338-42.
4. Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. ***J Prosthet Dent*** 1984;51(6):780-4.
5. Gogna R, Jagadish S, Shashikala K, Keshava Prasad B. Restoration of badly broken, endodontically treated posterior teeth. Journal of Conservative Dentistry : ***JCD*** 2009;12(3):123-8.
6. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. ***J Prosthet Dent*** 2002;7(3):256-63.
7. Scotti N, Rota R, Scansetti M, Paolino DS, Chiandussi G, Pasqualini D, *et al.* Influence of adhesive techniques on fracture resistance of endodontically treated premolars with various residual wall thicknesses. ***J Prosthet Dent*** 2013;110(5):376-82.
8. Faria ACL, Rodrigues RCS, de Almeida Antunes RP, de Mattos MdGC, Ribeiro RF. Endodontically treated teeth: Characteristics and considerations to restore them. ***J Prosthodont Res*** 2011;55(2):69-74.
9. Ibrahim AMBR, Richards LC, Berekally TL. Effect of remaining tooth structure on the fracture resistance of endodontically-treated maxillary premolars: An *in vitro* study. ***J Prosthet Dent*** 2016;115(3):290-5.
10. Suksaphar W, Banomyong D, Jirathanyanatt T, Ngoenwiwatkul Y. Survival Rates from Fracture of Endodontically Treated Premolars Restored with Full-coverage Crowns or Direct Resin Composite Restorations: A Retrospective Study. ***J Endod*** 2018;44(2):233-8.
11. Arunpraditkul S, Saengsanon S, Pakviwat W. Fracture resistance of endodontically treated teeth: three walls versus four walls of remaining coronal tooth structure. ***J Prosthodont*** 2009;18(1):49-53.
12. Sorrentino R, Monticelli F, Goracci C, Zarone F, Tay FR, Garcia-Godoy F, *et al.* Effect of post-retained composite restorations and amount of coronal residual structure on the fracture resistance of endodontically-treated teeth. ***Am J Dent*** 2007;20(4):269-74.
13. Nissan J, Barnea E, Bar Hen D, Assif D. Effect of remaining coronal structure on the resistance to fracture of crowned endodontically treated maxillary first premolars. ***Quintessence Int*** 2008;39(8):e183-7.
14. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: A retrospective cohort study. ***J Prosthet Dent*** 2005;93(2):164-70.
15. Tamse A, Fuss Z, Lustig J, Kaplavi J. An evaluation of endodontically treated vertically fractured teeth. ***J Endod*** 1999;25(7):506-8.
16. Bitter K, Meyer-Lueckel H, Fotiadis N, Blunck U, Neumann K, Kielbassa AM, *et al.* Influence of endodontic treatment, post insertion, and ceramic restoration on the fracture resistance of maxillary premolars. ***Int Endod J*** 2010;43(6):469-77.
17. Soares PV, Santos-Filho PC, Martins LR, Soares CJ. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: fracture resistance and fracture mode. ***J Prosthet Dent*** 2008;99(1):30-7.
18. Wood I, Jawad Z, Paisley C, Brunton P. Non-carious cervical tooth surface loss: a literature review. ***J Dent*** 2008;10:759-66.
19. Soares PV, Souza PG, Souza SC, Gonzaga RCdQ, Faria VLG, Naves MFdL, *et al.* Effects of non-carious cervical lesions and coronary structure loss association on biomechanical behavior of maxillary premolars. ***J Res Dent*** 2013;1(2):140-53.
20. Aw TC, Lepe X, Johnson GH, Mancl L. Characteristics of noncarious cervical lesions: a clinical investigation. ***J Am Dent Assoc*** 2002;133 (6):725-33.
21. Soares PV, Santos-Filho PC, Queiroz EC, Araujo TC, Campos RE, Araujo CA, *et al.* Fracture resistance and stress distribution in endodontically treated maxillary premolars restored with composite resin. ***J Prosthodont*** 2008;17(2):114-9.
22. Steele A, Johnson BR. In vitro fracture strength of endodontically treated premolars. ***J Endod*** 1999;25(1):6-8.
23. Mincik J, Urban D, Timkova S, Urban R. Fracture resistance

of endodontically treated maxillary premolars restored by various direct filling materials: an *in vitro* study. ***Int J Biomater*** 2016;2016:9138945.
24. Xie KX, Wang XY, Gao XJ, Yuan CY, Li JX, Chu CH. Fracture resistance of root filled premolar teeth restored with direct composite resin with or without cusp coverage. ***Int Endod J*** 2012;45(6):524-9.
25. Torres-Sanchez C, Montoya-Salazar V, Cordoba P, Velez C, Guzman-Duran A, Gutierrez-Perez JL, *et al*. Fracture resistance of endodontically treated teeth restored with glass fiber reinforced posts and cast gold post and cores cemented with three cements. ***J Prosthet Dent*** 2013;45(2):127-33.
26. Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M. Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. ***Int J Prosthodont*** 2007;20(3):293-8.
27. Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. ***Am J Dent*** 2000;Spec No:9b-13b.
28. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. ***J Endod*** 2004;30(5):289-301.
29. Goerig AC, Mueninghoff LA. Management of the endodontically treated tooth. Part I: concept for restorative designs. ***J Prosthet Dent*** 1983;49(3):340-5.
30. Veerapravati W, Vongphan N, Harnirattisai C, Sakdee J. Fracture resistance of endodontically treated premolars restored with different restorations. ***Int Chin J Dent Res*** 2005;5:75-9.
31. Cubas GB, Habekost L, Camacho GB, Pereira-Cenci T. Fracture resistance of premolars restored with inlay and onlay ceramic restorations and luted with two different agents. ***J Prosthodont Res*** 2011;55(1):53-9.
32. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. ***J Prosthet Dent*** 2007;98(5):389-404.
33. Ross IF. Problems connected with combined periodontal therapy and fixed restorative care. ***Dent Clin North Am*** 1972;16(1):47-57.
34. Ross IF. Fracture susceptibility of endodontically treated teeth. ***J Endod*** 1980;6(5):560-5.
35. Mobilio N, Fasiol A, Mollica F, Catapano S. *In Vitro* Fracture Strength of Teeth Restored with Lithium Disilicate Onlays with and without Fiber Post Build-Up. ***Dent J (Basel)*** 2018;6(3):35.
36. Kececi AD, Heidemann D, Kurnaz S. Fracture resistance and failure mode of endodontically treated teeth restored using ceramic onlays with or without fiber posts-an *ex vivo* study. ***Dent Traumatol*** 2016;32(4):328-35.
37. Magne P, Belser UC. Porcelain versus composite inlays/onlays: effects of mechanical loads on stress distribution, adhesion, and crown flexure. ***Int J Periodontics Restorative Dent*** 2003;23(6):543-55.
38. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. ***J Prosthet Dent*** 2002;88(3):297-301.
39. Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. ***J Am Dent Assoc*** 2005;136(5):611-9.
40. Mohammadi N, Kahnamoii MA, Yeganeh PK, Navimipour EJ. Effect of fiber post and cusp coverage on fracture resistance of endodontically treated maxillary premolars directly restored with composite resin. ***J Endod*** 2009;35(10):1428-32.
41. Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. ***J Prosthet Dent*** 1994;71(6):565-7.
42. Salameh Z, Sorrentino R, Ounsi HF, Sadig W, Atiyeh F, Ferrari M. The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber posts. ***J Endod*** 2008; 34(7):842-6.
43. Fokkinga WA, Le Bell AM, Kreulen CM, Lassila LV, Vallittu PK, Creugers NH. *Ex vivo* fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars. ***Int Endod J*** 2005;38(4):230-7.
44. Forberger N, Gohring TN. Influence of the type of post and core on *in vitro* marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. ***J Prosthet Dent*** 2008;100(4):264-73.
45. Jantarat J, Palamara JE, Messer HH. An investigation of cuspal deformation and delayed recovery after occlusal loading. ***J Dent*** 2001;29(5):363-70.
46. Korioth TW, Versluis A. Modeling the mechanical behavior of the jaws and their related structures by finite element (FE) analysis. ***Crit Rev Oral Biol Med*** 1997;8(1):90-104.
47. Hannig C, Westphal C, Becker K, Attin T. Fracture resistance of endodontically treated maxillary premolars restored with CAD/CAM ceramic inlays. ***J Prosthet Dent*** 2005;94(4):342-9.