Original article

Fracture Resistance of Endodontically Treated Upper Premolar with MOD Cavity Restored by Direct Resin Composite Combined with Fiber-Reinforced Composite Posts

Nadaprapai Khwanpuang[1], Chaiwat Maneenut[1]

[1]Department of Operative Dentistry, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

Abstract

The purpose of this study was to compare the fracture strength and fracture pattern of a previously endodontically treated premolar with MOD cavity when restored with a resin composite together with prefabricated fiber-reinforced composite (FRC) and novel unpolymerized fiber-reinforced composite (UPF) posts. Forty intact human maxillary premolars with single root and two canals were embedded in resin molds with simulated periodontal ligament. The specimens were divided into five groups: 1) Sound premolar (positive control); 2) Non-restored endodontically treated premolar with MOD cavity (negative control); 3) Endodontically treated premolar with MOD cavity restored with resin composite; 4) Endodontically treated premolar with MOD cavity restored with FRC post and resin composite; 5) Endodontically treated premolar with MOD cavity restored with UPF post and resin composite. All specimens were subjected to 500,000 cycles of cyclic loading and 10,000 cycles of thermocycling. The specimens were loaded to fracture at an angle of 45° on palatal cusp. The sound premolar had the highest fracture strength (510.92 ± 106.54 N) while the non-restored premolar had the lowest strength (73.88 ± 20.52 N). Using the post with resin composite restoration significantly increased the strength of the tooth. However, there was no significant difference in the strength between using FRC and UPF post. Most of the specimens had a favorable fracture. In conclusion, fiber-reinforced composite post positively increased the fracture strength when restored endodontically treated premolar with MOD cavity using resin composite but did not affect the fracture pattern. The type of post did not affect the fracture strength of the restored tooth.

Keywords: Endodontically treated premolar, Fiber-reinforced composite post, Fracture strength, Resin composite

Received Date: Mar 30, 2020 **Revised Date:** Apr 21, 2020 **Accepted Date:** Jun 15, 2020

doi: 10.14456/jdat.2020.25

Correspondence to:

Chaiwat Maneenut, Department of Operative Dentistry, Faculty of Dentistry, Chulalongkorn University, 34 Henri-Dunant Road, Wongmai, Patumwan, Bangkok, 10330 Thailand. Tel: 02-2188795 E-mail: mchaiwat@chula.ac.th, Chaiwat.M@chula.ac.th

Introduction

Endodontically treated teeth are susceptible to fractures due to substantial loss of structure from dental caries, fracture, cavity preparation and access opening. The survival of these teeth depends on various factors in which post-endodontic restoration is one of the keys to success.[1,2] Good restoration not only can restore form, function and esthetic, but also prevent marginal leakage and tooth fractures. Previously, a suggestion to protect the teeth with an intracanal post and a full coverage crown was considered as standard treatment.[3] However, this technique has some disadvantages such as multiple visits, loss of tooth structure resulting from tooth preparation and high costs.

With recent advancement in adhesive technology, minimal invasive dentistry gradually plays an important role in modern dentistry. A study showed that preservation of the remaining tooth structure increased the survival outcome and reduced the chance of fracture in endodontically treated teeth.[4] From this perspective, when the tooth has adequate structure to provide retention of restoration material, a non-cuspal coverage direct restoration is acceptable. However, this concept is still controversial, particularly in the maxillary premolar which has one of the highest fracture rates reported because it receives shear occlusal force and has a large and steep cusp while having a flat and slim root compared to its crown.[5-7]

A clinical study by Manocci and co-workers found that the success rate of endodontically treated premolar with class II cavity restored with full coverage crown was not statistically different from a restoration with fiber-reinforced composite post and direct resin composite in the three years follow up range.[8] Supported by a recent systematic review which pointed out that there was still lack of evidence to support the higher success rate of restoration with full coverage crown than with direct restoration.[9] Also, in-vitro studies showed that cuspal coverage restoration was not always necessary in premolar with both marginal ridges losing.[10,11]

Prefabricated fiber-reinforced composite post (FRC post) has increasingly been used in restoring an endodontically treated tooth due to various advantages compared to using a metal post. Its high success rate is due to its biomimetic behavior resulting from the low modulus of elasticity close to dentin.[12] Hence, it can distribute occlusal force along the tooth structure effectively.[13,14] Supported by the *in-vitro* studies which show that endodontically treated premolar restored with FRC post and resin composite had a higher fracture strength and less cuspal deflection compared to being restored with only a resin composite.[3,15] However, since this post was prefabricated, there were some situations that the post did not fit into the prepared root canal resulting in a gap-filling with low strength resin cement which may weaken the tooth.[16] To solve these problems, an unpolymerized glass fiber-reinforced composite post (UPF post) was invented. Its shape can be adjusted to adapt and fit into the root canal prior to light polymerization and cementation.[17]

There were still few data comparing the use of FRC post and UPF post for restoring endodontically treated tooth.[17,18] Thus, this study was conducted to compare the fractural strength and fracture pattern of previously endodontically treated premolar with MOD cavity when restored with only resin composite or together with FRC post or UPF post. The research proposal was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University. The study code was HREC-DCU 2018-051.

Material and Method

Specimen preparation

Forty intact human maxillary premolars with single root and two canals which were extracted for orthodontic treatment were used. The selected teeth were quite similar in shape and size, had a straight canal and were free from cracks, dental caries or any defects. The teeth were stored in 0.5% thymol solution (M-dent, Thailand) and were used within six months. Teeth were mounted in resin acrylic mold with periodontal ligament (PDL) stimulating using self-cured polyether (Silagum™, 3M ESPE, USA).[19] Level of resin acrylic was 2 mm from cemento-enamel junction (CEJ) to simulate alveolar bone level. (Fig. 1).

Thirty-two specimens were subjected to MOD cavity preparation using computer numerical control (CNC) preparation machine (CNC specimen former, Thailand). Occlusal cavities with 4 mm bucco-lingual width and 4 mm depth together with proximal boxes, 2 mm in depth from pupal wall, 1 mm width in mesio-distal direction and 4 mm width in bucco-lingual direction, were created. After preparation, all specimens had remaining buccal and lingual cusps thickness at the height of contour at more than 2 mm. (Fig. 2).

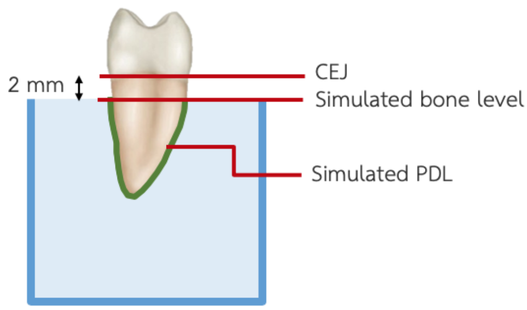

Figure 1 *Mounted tooth in resin mold with simulated periodontal ligament and alveolar bone level*

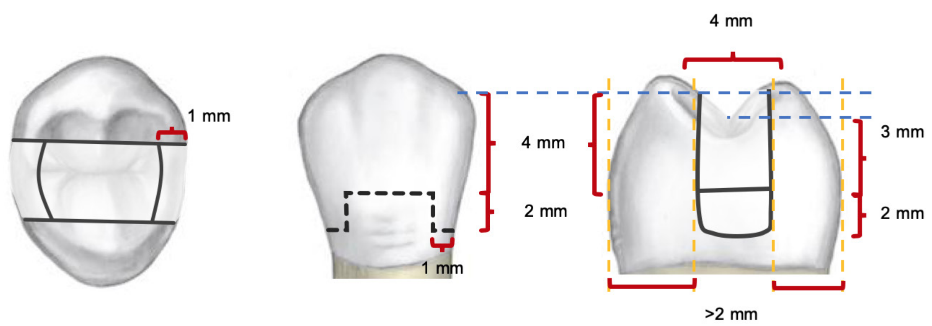

Figure 2 *Cavity preparation*

Pulpal exposure was performed at the middle of occlusal cavity using round diamond bur (FG 8200S, Intensiv, Switzerland). A straight-line access opening was done using high-speed diamond pointed-taper bur (FG D2, Intensiv, Switzerland) at pulp exposure spot. Instrumentation was carried out in buccal and palatal canals using X1-X3 NiTi rotary instrument (ProTaper™ Next, Dentsply Sirona, USA) at 300 rpm, 2N/cm by pecking motion to the working length under 17 % EDTA cream (RC prepTM, Premier, USA) lubrication and 5 ml of 2.5 % NaOCl (Faculty of Dentistry Chulalongkorn University, Thailand) irrigation. Final flushed the canals with 17 % EDTA (Faculty of Dentistry Chulalongkorn University, Thailand) 3 ml for one minute followed by 5 ml of 2.5 % NaOCl. The canals were dried using paper points. Gutta-percha canal obturation was done by a single cone technique using match-tapered cone X3 (ProTaper™ Next, Dentsply Sirona, USA) with resin-based sealer (AHTM plus, Dentsply Sirona, USA). The gutta-percha was removed to the cemento-enamel junction level.

Eight endodontically treated teeth with MOD cavity were not restored and used as negative control specimens. Eight endodontically treated teeth with MOD cavity were restored with nanofilled resin composite (Filtek™ Z350 XT, 3M ESPE, USA). The bonding protocol was done with a 3-step etch-and-rinse bonding system (Optibond™ FL, Kerr, USA) following the manufacturer's instructions. The cavity was etched with 37 % phosphoric acid for 15 s, rinsed with distilled water for 15 s, dried with clean gentle air for 5 s to achieve a moist dentin, primed with FL primer for 10 s in agitating motion, gentle air blew until there was no sign of liquid movement, lightly coating the cavity with FL adhesive and light polymerization (Demi™, Kerr, USA) for 20 s. Tofflemire matrix system was applied to the tooth, the top margin of the band was at 1 mm above the occlusal margin. The cavity was filled with resin composite using incremental technique, which was 2 mm for each layer measured by a periodontal probe and light curing for 40 s. The tip of the light curing unit was placed at the tip of buccal and palatal cusps. Each proximal cavity was filled and cured followed by the occlusal cavity (Fig. 3A). The proximal cavity was filled with three layers of composite which each layer was cured for 40 s (Fig. 3B). Then, the occlusal cavity which is 4 mm in depth from occlusal margins was filled with two layers of composite in which each layer was cured for 40 s (Fig. 3C). The matrix band was removed and the resin composite in each proximal cavity was additionally cured by placing the tip of the light curing unit in close contact to the buccal and palatal sides of the cavity to simulate a clinical condition. Each side was cured for 40 s.

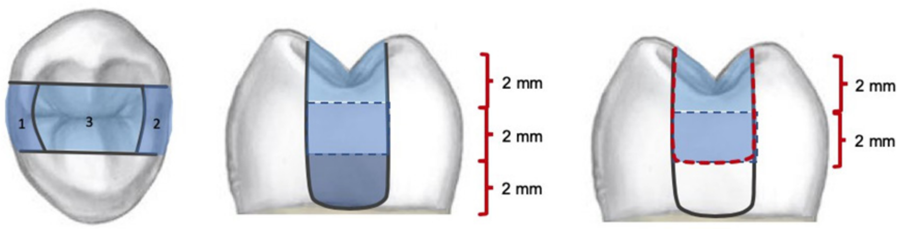

Figure 3 *Incremental technique for resin composite restoration*

The other sixteen specimens were subjected to post space preparation in palatal canal using slow speed peeso reamer #1-2 (Dentsply, USA) for gutta-percha removing. The depth of post space was equal to the height of the clinical crown. The FRC post no.2 (RelyX™ Fiber Post, 3M ESPE, USA) was used in the eight specimens and the UPF post (everStick™, GC Europe, Belgium) size 0.9 mm was used in the other eight specimens. The shape of the UPF post was adjusted to fit the canal and polymerized with light curing (Demi, Kerr, USA) for 20 s prior to the cementation process.

The post cementation process was done using a 2-step etch-and-rinse adhesive system (Optibond™ Solo, Kerr, USA) and dual cured resin cement (NX3, Kerr, USA) following the manufacturer's instructions. The root canal was etched with 37 % phosphoric acid for 15 s, rinsed with distilled water for 15 s and dried with paper point. The adhesive (OptibondTM Solo, Kerr, USA) was applied with a microbrush, the excess was removed using paper point and light cured for 40 s. The resin cement (NX3 Nexus™, Kerr, USA) was mixed and applied into the root canal using lentulo spiral number 25 (Dentsply Sirona, USA), the adhesive coated post was inserted into the root canal and light cured again for 20 s (DemiTM, Kerr, USA). The post was then cut to the level of the pulpal floor of the cavity using a high speed fissured diamond bur (FG 8211, Intensiv, Switzerland) (Fig. 4).

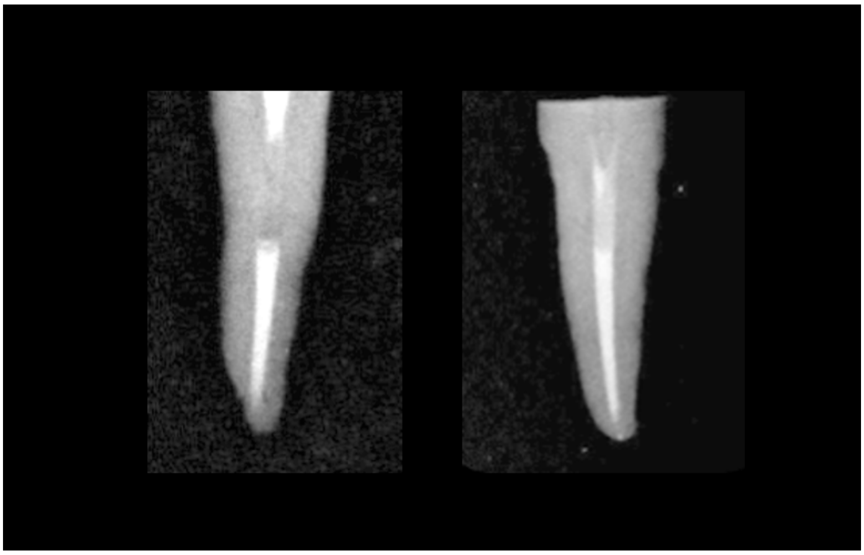

Figure 4 *Radiographic images show close adaptation of FRC post (left) and UPF post (right) to the root canal*

In summary, 40 teeth specimens were divided into five groups, eight specimens for each group:

Group 1: Sound premolar (positive control)

Group 2: Non-restored endodontically treated premolar with MOD cavity (negative control)

Group 3: Endodontically treated premolar with MOD cavity restored with resin composite

Group 4: Endodontically treated premolar with MOD cavity restored with FRC post and resin composite

Group 5: Endodontically treated premolar with MOD cavity restored with UPF post and resin composite

Artificial aging

All specimens underwent the artificial aging using cyclic loading and thermocycling. The cyclic loading was done in fatigue tester (Universal testing machine, Fatigue tester, E1000, Instron, England) with stainless steel antagonist (diameter 6 mm) contact at the middle of occlusal surface, parallel to tooth axis. The specimen was loaded continuously with 50N, 4 Hz frequency for 500,000 cycles. The specimen was later subjected to 10,000 cycles of thermocycling (Thermocycling unit, King Mongkut's University of Technology Thonburi, Thailand) at 5°C and 55°C with a dwell time of 30 s. Due to the transfer time of 5 s, the total time for one complete thermocycling cycle was 70 s.

Fractural strength test

The specimen was mounted in a metal holder of the universal testing machine (Universal testing machine EZ-S, SHIMADZU, Japan) at an angle of 45° to the tooth axis. The 4 mm in diameter stainless steel antagonist was applied on the incline plane of palatal cusp with crosshead speed of 0.5 mm/min. A sudden decrease in force of more than 50 % was an indication of fracture failure.

Fracture pattern determination

The specimen was removed from the acrylic mold. The fracture pattern was determined by visual inspection. Fracture of the tooth above the simulated alveolar bone was classified as a favorable fracture and the fracture below the simulated alveolar bone (top of resin block) was classified as an unfavorable fracture (Fig. 5).

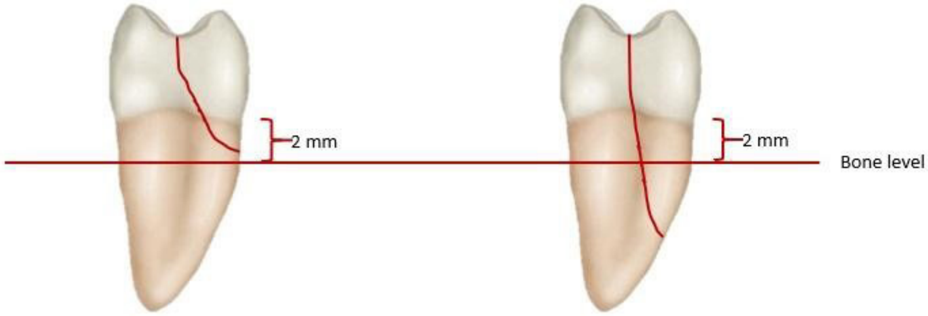

Figure 5 Fracture patterns, favorable (left) and unfavorable (right)

Statistical analysis

The fracture strength was analyzed using the one-way ANOVA test. The significant was set at $p<0.05$. The fracture pattern was analyzed using Chi-square test.

Result

The mean fracture strength of all groups after artificial aging was shown in Table 1. Group 1 (positive control) had the highest strength (510.92 ± 106.54 N) and group 2 (negative control) had the lowest (73.88 ± 20.52 N). Restoring the tooth with only direct resin composite (group 3) could increase the fracture strength significantly (251.01 ± 63.18 N, $p<0.05$). Using the post with resin composite restoration (groups 4 and 5) could also significantly increase the strength of the tooth. However, there is no significant difference in the strength between using a FRC post and a UPF post ($p=0.998$).

Fracture pattern of all the specimens is shown in Table 2 (fig. 6). Most of the specimens had a favorable fracture. There was no statistical difference among the groups ($p=0.217$).

Table 1 Mean fracture strength and standard deviation. Same abbreviation letter means no statistical significant difference

Group	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
1	8	510.92[a]	106.54	37.67	335.75	629.56
2	8	68.88[d]	24.20	8.56	36.97	108.41
3	8	251.10[c]	63.18	22.34	158.51	329.37
4	8	376.83[b]	72.99	25.80	251.34	463.67
5	8	387.10[b]	67.28	23.79	278.93	485.53

Table 2 Fracture pattern of tested specimens

Group	Favorable Fracture (n)	Unfavorable Fracture (n)
1	8	0
2	8	0
3	8	0
4	7	1
5	8	0

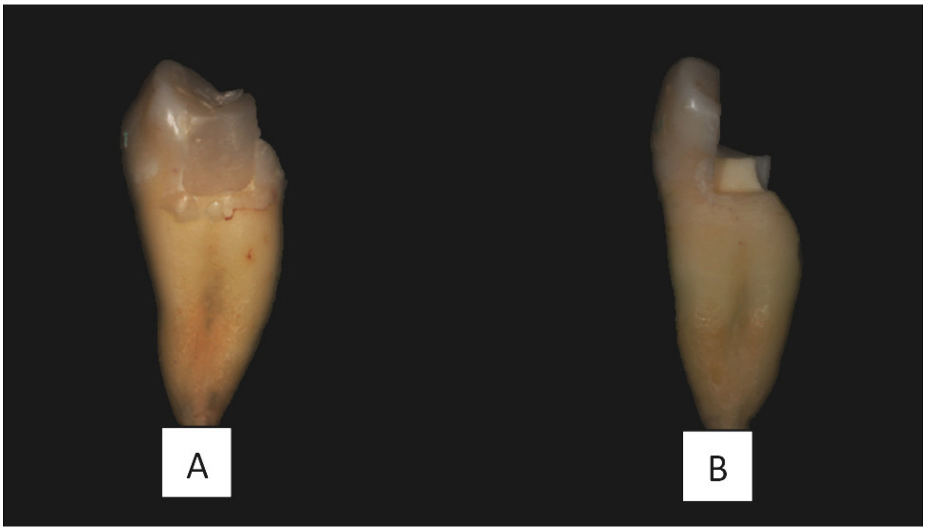

Figure 6 *Fracture pattern; (left) favorable fracture, (right) unfavorable fracture*

Discussion

Previous studies on the fracture strength of endodontically treated premolar mostly done in tremendous loss of structure tooth and had cuspal coverage restoration.[20-22] However, with recent advance technology in restoration material and adhesive system, endodontically treated premolar with MOD cavity which lost both marginal ridges but cuspal thickness was left more than 2 mm, may not need cuspal coverage restoration.[10] Restored teeth with direct resin composite in combination with fiber-reinforced composite post could be sufficient for resisting the occlusal load. This situation was challenging for dentists in making decisions of restoration type, the need of post and post selection.

In this study, factors that could affect the tooth fracture strength were controlled which included tooth size, cavity size and root canal size. The selected teeth had less than 10 % differences in clinical crown length, root length and the width of the crown in M-D and B-Li direction which were not statistically different between the groups ($p<0.05$). Size and shape of the cavity were controlled by CNC machine preparation and those of the root canal were controlled by Ni-Ti rotary file instrumentation. In addition, since periodontal ligament plays an important role in distributing the occlusal force to the alveolar bone,[23] the 0.2-0.4 mm thickness of artificial periodontal ligament (polyether impression material) was created when the tooth was embedded directly in the resin acrylic block.

The artificial aging, 500,000 cycles cyclic loading and 10,000 cycles thermocycling, was done to simulate the long term (2 years) function of the restored tooth.[24-26] From a previous study, when endodontically treated teeth was subjected to cyclic fatigue of more than 100,000 cycles, the fractural strength will be significantly subsided.[24] Also, when subjected to thermocycling of more than 1,000 cycles, the adhesive will be weakened.[25]

The fracture strength test was done on a buccal inclined plane of palatal cusp at 45° to the long axis of the tooth to simulate eccentric movement and traumatic force. They were considered as an unfavorable load which could cause a tensile and shear stresses and lead to a vertical root fracture.[27,28]

The results of this study showed that when restored the endodontically treated maxillary premolar which has MOD cavity using resin composite in combination with or without the fiber-reinforced composite post could significantly increase the fracture strength even if it was not comparable to the sound premolar. The fracture strength of the teeth that was restored with only resin composite (251.01 ± 63.18 N) was significantly less than that of the restored teeth using the combination of post and resin composite. However, compared to the maximum bite force of maxillary premolar which was 222–445 N (average 322.5 N) and might be rise up to 520-800N (average 660N) during clenching,[29,30] it could be implied that restoring the endodontically treated maxillary premolar with MOD cavity using only a resin composite might withstand the maximum bite force after function for two years in the oral cavity of a healthy adult patient.

When restoring the teeth with the resin composite in combination with FRC or UPF posts, the fractural strength increased significantly compared to restoring with only the resin composite and was higher than the maximum bite force of both male and female patients as described before.[29,30] This finding is consistent with the previous study[31] and it may be due to the force distribution properties of the fiber post. It is supported by the finite element which showed that, when restoring the tooth with fiber post and adhesive system, the occlusal force can distribute along the surrounding tooth structure which has a pattern similar to a natural tooth.[32] Moreover, in our study, the length of post space in the root canal was comparable to the length from tip of the buccal cusp to CEJ which was the minimal length recommended in a previous study.[32]

Beside the advantageous properties of the prefabricated fiber post, it should be considered that other factors such as canal preparation, post selection, post preparation and cementation are involved in the completion and successful use of the post. The post might not totally fit into the prepared root canal and the gap will need to be filled with low strength resin cement. This could be a weak point and deteriorate the restoration in long term use.[33] Unpolymerized glass fiber (UPF) posts were invented to eliminate that disadvantage because it's shape can be adjusted to totally fit the prepared canal prior to cementation. Its post polymerization's mechanical properties were comparable to a conventional FRC post.[34] An *in-vitro* study found that using a UPF post with resin cement could increase the fracture strength and be higher than using a conventional FRC post.[18] However, our study found that the fracture strength of the endodontically treated maxillary premolar with MOD cavity using resin composite in combination with both types of post was not significantly different (*p*=0.998). This may be the result of the conservative post space preparation and the ultimate adaptation of a FRC post to the canal (Fig. 3). Thus, the advantage from the shape-adjusting property of the UPF post was indistinct, which conform to the in-vitro study by Frater and co-workers in 2017.[17]

To emphasize, when looking at the detail of post space, which ended 5 mm short from the working length, it was a considerable fit to the FRC post used in this study. The FRC post has 0.7 mm in diameter at the tip[35] which was close to the diameter of Protaper NEXT X3 at 5 mm short from the working length[36] and Protaper NEXT did not enlarge the canal more than the declared taper shape of the instrument profile.[37] Moreover, both, Protaper NEXT and FRC post also are 5-6 % tapered in shape. This means that there was an ultimate fit of the FRC post to the last size of the instrumented canal and the adaptation may not differ from using a UFP post.

When determining the fracture pattern, it was interesting that most specimens of all the groups have a favorable fracture and were not statistically different (*p*=0.217). Like the other study which found that a fiber-reinforced composite post can prevent an unfavorable fracture due to its dentin-like modulus of elasticity which has advantage in stress distribution.[38] In our study, a 45° shear load on the palatal cusp was conducted to simulate bite force. It caused the cusp to debond from the restoration followed by a slanting fracture to the root and end above the simulated alveolar bone. This result was different from the previous study[38] which used axial load and fracture went along the root axis.

Conclusion

With the limitations in this study, it might be concluded that;

1. MOD cavity preparation and endodontically treatment reduced the fracture strength of maxillary premolar.
2. Restoring the endodontically treated maxillary premolar with MOD cavity using a resin composite with or without a fiber-reinforced post could restore the fracture strength of the tooth but is not comparable to that of a sound premolar.
3. Fiber-reinforced composite posts positively increased the fracture strength of the tooth compared to only using a resin composite.
4. The type of post did not affect the fracture strength of the restored tooth.
5. The fracture pattern of all restorations was restorable.

Declaration and Acknowledgement

The authors do not have any financial interest in the companies whose materials are discussed in this article. The authors would like to gratefully acknowledge the Dental Material Science Research Center, Faculty of Dentistry, Chulalongkorn University for their valuable service.

Reference

1. Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. *J Prosthet Dent* 1994;71(6):565-7.
2. Tronstad L, Asbjornsen K, Doving L, Pedersen I, Eriksen HM. Influence of coronal restorations on the periapical health of endodontically treated teeth. *Endod Dent Traumatol* 2000;16(5):218-21.
3. Acquaviva PA, Madini L, Krokidis A, Gagliani M, Mangani F, Cerutti A. Adhesive restoration of endodontically treated premolars: influence of posts on cuspal deflection. *J Adhes Dent* 2011;13(3):279-86.
4. 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.
5. Cavel WT, Kelsey WP, Blankenau RJ. An *in vivo* study of cuspal fracture. *J Prosthet Dent* 1985;53(1):38-42.
6. Ferrario VF, Sforza C, Serrao G, Dellavia C, Tartaglia GM. Single tooth bite forces in healthy young adults. *J Oral Rehabil* 2004;31(1):18-22.
7. Van Eijden TMGJ, Brugman P, Weijs WA, Oosting J. Coactivation of jaw muscles: Recruitment order and level as a function of bite force direction and magnitude. *J Biomech* 1990;23(5):475-85.
8. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TRP. 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.
9. Fedorowicz Z, Carter B, de Souza RF, Chaves CA, Nasser M, Sequeira-Byron P. Single crowns versus conventional fillings for the restoration of root filled teeth. *Cochrane Database Syst Rev* 2012;16(5):CD009109.
10. 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.
11. 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.
12. Stewardson DA, Shortall AC, Marquis PM, Lumley PJ. The flexural properties of endodontic post materials. *Dent Mater* 2010;26(8):730-6.
13. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. *J Dent* 2009;37(2):115-21.
14. Ferrari M, Vichi A, Garcia-Godoy F. Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores. *Am J Dent* 2000;13(Spec No):15B-8B.
15. Scotti N, Scansetti M, Rota R, Pera F, Pasqualini D, Berutti E. The effect of the post length and cusp coverage on the cycling and static load of endodontically treated maxillary premolars. *Clin Oral Investig* 2011;15(6):923-9.
16. Maccari PC, Cosme DC, Oshima HM, Burnett LH, Jr., Shinkai RS. Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems. *J Esthet Restor Dent* 2007;19(1):30-6;discussion7.
17. Fráter M, Forster A, Jantyik Á, Braunitzer G, Nagy K, Grandini S. *In vitro* fracture resistance of premolar teeth restored with fibre-reinforced composite posts using a single or a multi-post technique. *Aust Endod J* 2017;43(1):16-22.
18. El-Ela O, Atta O, El-Mowafy O. Fracture resistance of anterior teeth restored with a novel nonmetallic post. *J Can Dent Assoc* 2008;74(5):441.
19. Nothdurft FP, Seidel E, Gebhart F, Naumann M, Motter PJ, Pospiech PR. The fracture behavior of premolar teeth with class II cavities restored by both direct composite restorations and endodontic post systems. *J Dent* 2008;36(6):444-9.
20. Guo J, Wang Z, Li X, Sun C, Gao E, Li H. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. *J Adv Prosthodont* 2016;8(6):489-93.

21. Rocca GT, Daher R, Saratti CM, Sedlacek R, Suchy T, Feilzer AJ, *et al.* Restoration of severely damaged endodontically treated premolars: The influence of the endo-core length on marginal integrity and fatigue resistance of lithium disilicate CAD-CAM ceramic endocrowns. ***J Dent*** 2018;68:41-50.

22. Pedrollo Lise D, Van Ende A, De Munck J, Umeda Suzuki TY, Cardoso Vieira LC, Van Meerbeek B. Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials. ***J Dent*** 2017;59:54-61.

23. Sirimai S, Riis DN, Morgano SM. An in vitro study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-and-core systems. ***J Prosthet Dent*** 1999;81(3):262-9.

24. Huysmans MCDNJM, Peters MCRB, Varst PGTVD, Plasschaert AJM. Failure behaviour of fatigue-tested post and cores. ***Int Endod J*** 1993;26(5):294-300.

25. Price RB, Dérand T, Andreou P, Murphy D. The effect of two configuration factors, time, and thermal cycling on resin to dentin bond strengths. ***Biomaterials*** 2003;24(6):1013-21.

26. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. ***J Dent*** 1999;27(2):89-99.

27. Wandscher VF, Bergoli CD, Limberger IF, Ardenghi TM, Valandro LF. Preliminary Results of the Survival and Fracture Load of Roots Restored With Intracanal Posts: Weakened vs Nonweakened Roots. ***Oper Dent*** 2014;39(5):541-55.

28. 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.

29. Widmalm SE, Ericsson SG. Maximal bite force with centric and eccentric load. ***J Oral Rehabil*** 1982;9(5):445-50.

30. Hidaka O, Iwasaki M, Saito M, Morimoto T. Influence of Clenching Intensity on Bite Force Balance, Occlusal Contact Area, and Average Bite Pressure. ***J Dent Res*** 1999;78(7):1336-44.

31. Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post. ***Biomaterials*** 2002;23(13):2667-82.

32. Adanir N, Belli S. Evaluation of different post lengths' effect on fracture resistance of a glass fiber post system. ***Eur J Dent*** 2008;2(1):23-8.

33. Silva GRd, Santos-Filho PCdF, Simamoto-Júnior PC, Martins LRM, Mota ASd, Soares CJ. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. ***Braz Dent J*** 2011;22(3):230-7.

34. Lassila LVJ, Tanner J, Le Bell AM, Narva K, Vallittu PK. Flexural properties of fiber reinforced root canal posts. ***Dent Mater*** 2004;20(1):29-36.

35. 3M. 3M post and core solution 2017 [cited 2020 2 Jan]. Available from: https://multimedia.3m.com/mws/media/1146520O/3m-relyx-fiber-post-3d-glass-fiber-post-technical-data-sheet.pdf.

36. Dentsply Sirona. ProTaper Next Shape Dimensions 2020 [cited 2020 2 Jan]. Available from: https://assets.dentsplysirona.com/dentsply/pim/manufacturer/Endodontics/Glide_Path__Shaping/Rotary__Reciprocating_Files/Shaping/PROTAPER_NEXT_Rotary_Files/PROTAPER%20NEXT_Shape%20Dimensions_EN.pdf.

37. Pasqualini D, Alovisi M, Cemenasco A, Mancini L, Paolino DS, Bianchi CC, *et al.* Micro–Computed Tomography Evaluation of ProTaper Next and BioRace Shaping Outcomes in Maxillary First Molar Curved Canals. ***J Endodont*** 2015;41(10):1706-10.

38. Soares CJ, Soares PV, Santos-Filho PCF, Castro CG, Magalhaes D, Versluis A. The Influence of Cavity Design and Glass Fiber Posts on Biomechanical Behavior of Endodontically Treated Premolars. ***J Endodont*** 2008;34(8):1015-9.