The Effect of Fiber Insertion on Fracture Resistance of Endodontically Treated Molars With MOD Cavity and Reattached Fractured Lingual Cusps

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Abstract: In this study, the effect of flowable composite reinforced with a leno wave ultra high modulus (LWUHM) polyethylene fiber (Ribbond) on fracture resistance of endodontically treated molars with MOD cavity and lingual cuspal fracture was evaluated. Sixty sound extracted human mandibular molars were randomly assigned to six groups ($n = 10$). Group 1 served as control. Teeth in groups 2–6 received root canal treatment and a MOD cavity preparation. Teeth in group 2 were kept unrestored. Lingual walls of specimens in groups 3–6 were fractured at the CEJ and reattached (C&B Super-Bond). Group 3 was kept unrestored, and group 4 was restored with a composite resin (CR) (AP-X). In group 5, a flowable resin (FR, Protect Liner F) and in group 6, a Ribbond in combination with FR were inserted inside the cavity before CR restoration. After finishing and polishing, the specimens were subjected to compressive loading perpendicular to the occlusal surface at a crosshead speed of 1 mm/min. The mean load necessary to fracture were recorded in Newton and the results were statistically analyzed. MOD cavity preparation reduced fracture resistance of endodontically treated teeth ($p < 0.05$). Fracture resistance of rebonded fractured specimens was found to be similar to that of the nonfractured samples ($p > 0.05$). Use of LWUHM polyethylene fiber Ribbond increased fracture strength of endodontically treated molar teeth with MOD cavity preparation and cuspal fracture ($p < 0.05$). As a result, it was concluded that the insertion of Ribbond inside the cavity has a positive effect on fracture strength of endodontically treated molar teeth with MOD cavity preparation and cuspal fracture. © 2006 Wiley Periodicals, Inc. J Biomed Mater Res Part B: Appl Biomater 79B: 35–41, 2006

Keywords: fiber-reinforced composite (FRC); reinforcement; endodontic treatment; cuspal fracture

INTRODUCTION

The restoration of the pulpless tooth is a critical final step of successful endodontic therapy. Loss of dentin including anatomic structures such as cusps, ridges, and arched roof of the pulp chamber may result in fracture after the final restoration. These cracks sometimes may even cause failure of the root canal treatment. Thus, the preservation of the remaining tooth structure is important for the longevity of endodontic treatment. Previous studies have indicated that full cast crown restorations,[1,2] an indirect cast restoration covering the cusps (onlay),[3] complex amalgam restorations,[4,5] or composite materials can be used for final restoration. Emphasis has also been placed on intracoronal strengthening of teeth to protect them against fracture,[6,7] but controversy exists still regarding the preferred type of final restoration.

When a cuspal fracture occurs, the tooth can be restored by reattaching the fragment to the remaining tooth structure, using a dentin bonding system and a resin composite.[8] Only a few *in vitro* studies report the success of such restorations in laboratory conditions.[9,10] Shrinkage of composite materials during polymerization is one of the prime factors that ad-

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versely affect the success of direct composite restoration. Significant research efforts have been made to provide relief of the contraction stresses caused by the shrinkage, which cause microcracking in the bulk, weakening of interfaces, and even debonding of local areas between bonded surfaces. Polymerization shrinkage is compensated by flow of the composite.[11] A rigid bond between the resin composite and tooth structures generates contraction stresses at the bonding interfaces.[12,13] These stresses can be reduced by several methods. Performance of the dentin bonding agents is assumed to resist the contraction forces by forming a continuous hybrid layer between the restoration and tooth structure.[14] One of the suggested methods for reducing debonding during polymerization shrinkage is the application of a low viscosity, low modulus intermediate resin between the bonding agent, and restorative resin to act as an "elastic buffer" or "stress breaker" that can relieve contraction stresses and improve marginal integrity[15,16]. This layer essentially serves to lessen the thermoelastic mismatch between the components while still enabling efficiency of stress transfer and the role of the composite in holding cracks closed and thereby providing integrity of restoration. This requires appropriate tailoring of properties without which the advantages cannot be gained. A recent study showed that a flowable composite did not produce gap-free resin margins in Black II slot cavities.[17]

The development of fiber-reinforced composite (FRC) technology has provided a significant opportunity to tailor materials response and to improve the behavior of existing materials. It is emphasized that the fibers provide load paths for carrying stresses as well as directionality of properties such as strength and modulus. They also act as stiff bands when stretched over prefractured surfaces resisting crack opening. In addition, the presence of fibers in the resin increases resistance to microcracking, while decreasing shrinkage and creep. It has been reported that FRC have been used in the laboratory for fabrication of single crowns, full and partial coverage-fixed partial dentures,[18,19] fabrication of periodontal splints, and chairside-fixed partial dentures.[20–22] FRC has been shown to possess adequate modulus and strength to function successfully in the mouth.[23,24] A finite elemental stress analysis study also reported that FRC postcore systems provide more adequate restoration by protecting the remaining tooth tissue with its elastic modulus close to dentin as compared to the conventional rigid postcore systems.[25]

These new materials and techniques enable the practitioner to approach old problems from a different perspective and thereby achieve unique and innovative solutions. The reinforcement of composite restorations with fibrous assemblies can change the effective fracture strength of the teeth and may be effective in reattaching the fractured cusps in endodontically treated teeth through the creation of a strong bridge between the fractured cusps. In our previous study,[26] we have proven that creating an elastic layer under a composite restoration using a leno weave ribbon of ultra high molecular weight (UHMW) polyethylene fiber or flowable composite would increase the fracture strength of endodontically treated teeth with MOD cavity preparation. The purpose of this *in vitro* study was to evaluate the effect of fiber reinforcement on reattachment of fractured cusps in endodontically treated molars with cuspal fracture.

MATERIALS AND METHODS

Sixty intact human mandibular molar teeth extracted for periodontal reasons with similar anatomic dimensions were used in the current study. To minimize the influence of variations size and shape on the results, the teeth were classified based on their mesiodistal and buccolingual dimensions and randomly distributed into six groups of 10 teeth each. The teeth were prepared as follows.

Group 1

This group did not receive either cavity preparation or root canal treatment and used as control.

All remaining specimens (groups 2–6) were endodontically instrumented to a size 45 K-file and obturated with gutta percha and AH Plus (De-Trey, Switzerland) sealer using a lateral condensation technique. MOD cavities were carefully and uniformly prepared in the teeth down to the canal orifices so that the thickness of the buccal wall of the teeth measured 2 mm at the buccal occlusal surface, 2.5 mm at the cemento-enamel junction, 1.5 mm lingual occlusal surface, and 1.5 mm at the cemento-enamel junction. The teeth were then embedded in acrylic resins to the level of cemento-enamel junction.

Group 2

This group was kept unrestored after MOD cavity preparation.

From groups 3–6, lingual walls of crowns of 40 teeth were fractured at the cemento-enamel junction using a sharp indentor (Figure 1). The fractured lingual walls were reattached by rebonding the fractured fragment using C&B Super Bond (Sun Medical, Japan). The fracture line was first treated with Green Activator for 10 s, rinsed, and dried. Four drops of monomer (Super Bond monomer) and one drop of catalyst (Super Bond catalyst S) were mixed in a ceramic well and the bonding surfaces were wetted with this mixture. One small cup of Super Bond polymer L-Type clear powder was then added to the monomer and mixed. The prepared resin cement was applied to the fracture line using a brush and the fractured lingual walls were reattached.

Group 3

The teeth were kept unrestored after reattachment of the fractured fragment.

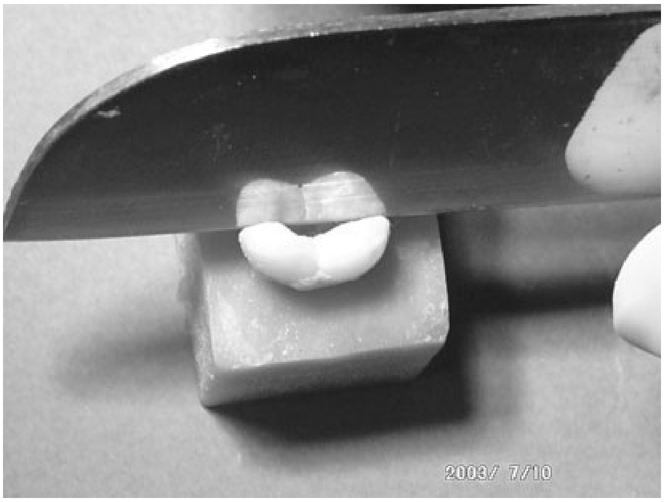

Figure 1. The lingual cusps of the teeth were standard fractured at the cemento-enamel junction using a sharp indentor.

Group 4

The cavities were cleaned and dried. After priming for 20 s (SE Primer, Kuraray, Japan), cavity surfaces were gently dried. SE Bond Adhesive (Kuraray Co., Japan) was applied to the cavity surfaces and cured for 20 s using a halogen light curing unit (Lunar, Benlioğlu Dental, Turkey) with an intensity of at least 500 mW/cm^2. An ivory matrix was applied to the teeth with plastic celluloid strips and the cavities were then restored with a resin composite (Clearfil AP-X, Kuraray, Japan) using a bulk technique. The depth of the composite resin (CR) was maximum 4 mm. The restorations were cured from the occlusal side for 40 s using the same curing unit.

Group 5

After priming and bonding procedures, the cavity surfaces were coated with a layer of low viscosity resin composite

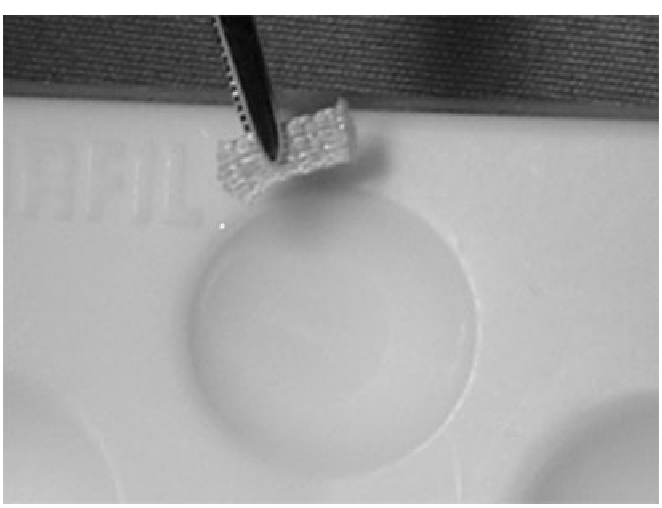

Figure 2. Polyethylene fiber (3 mm width) before coating with adhesive resin.

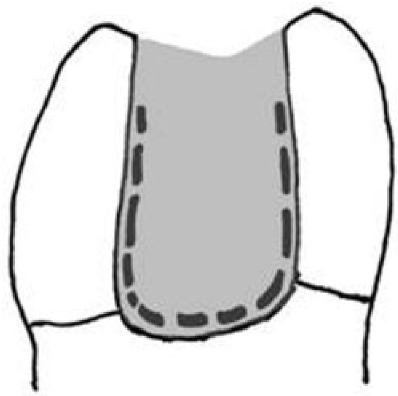

Figure 3. Schematic representation of embedding the resin coated polyethylene fiber inside the uncured flowable composite.

(Protect Liner F, Kuraray, Japan) within 1 mm of the prapa-ration margins and cured for 20 s. This low modulus liner was then covered with the same resin composite as described in group 4.

Group 6

After priming and bonding procedures, the cavity surfaces were coated with flowable composite using a procedure similar to that used in group 5 and kept uncured. A piece of leno weave ribbon formed of UHMW polyethylene fiber (8 mm long, 3 mm width) (Ribbond, Ribbond, Seattle, WA) was cut and impregnated with adhesive resin (Figure 2). Excess material was removed with a hand instrument and the fiber was embedded into the bed of uncured flowable resin (FR) from the occlusal 1/3 of the buccal wall to the occlusal 1/3 of the lingual wall (Figure 3). After curing from the occlusal side for 20 s, the cavities were restored with composite as described earlier. It was expected that the use of the leno weave provides multidirectional reinforcement, thereby enabling the fiberous reinforcement to be activated in multiple directions. Vertical compressive pressure on the tooth, as applied in the fracture test, causes radial outward forces attempting to cause differential movement of the fragments of teeth, which are held together by the fibrous assembly. The use of a nonunidirectional configuration in the leno weave assists in spreading out forces uniformly in the cavity. It is noted that a unidirectional assembly substantially looses efficiency if loaded, or forced to react, in any direction except that parallel to the fibers themselves. Thus, in this case, the intrinsic fabric structure itself assists in maintaining adhesion of the fractured elements.

The specimens were stored in 100% humidity for 24 h, placed into an Instron Machine (Instron, Canton, MA), and loaded compressively at 1 mm/min (Figure 4). A vertical compressive force was applied with a 5 mm diameter stainless steel bar. The bar contacted the occlusal surface of the restoration and buccal and lingual cusps of the teeth. The force necessary to fracture each tooth was recorded in Newton and the data was subjected to a one-way analysis of variance and *post hoc* Tukey HSD test for the six experimen-

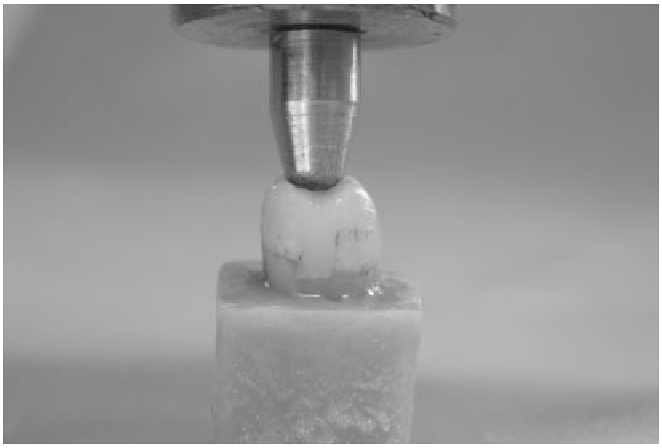

Figure 4. Mounted tooth in acrylic resin and 5-mm diameter stainless steel bar.

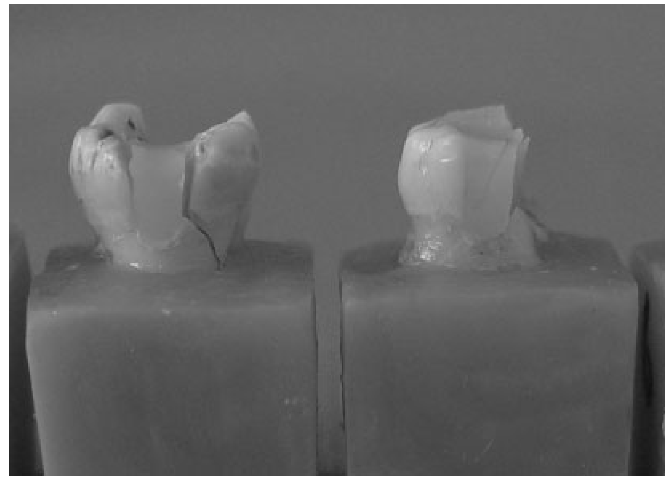

Figure 5. Fractured samples after loading test.

tal conditions. The fractured specimens were then examined under 8× magnification to determine the fracture mode.

RESULTS

Mean fracture resistance (N) and the standard deviation for each of the six experimental conditions are presented in Table I.

One-way analysis of variance indicated that overall differences of statistical significance between the groups were found at the 0.05 level and Tukey *post hoc* tests indicated that fracture strength of group 1 (i.e. unfractured specimens) was significantly higher than the other groups ($p < 0.0001$). Fracture strength of rebonded fractured specimens (group 3) were found to be similar to nonfractured samples (group 2) ($p > 0.0001$). Restoring teeth with resin composite with or without a flowable composite lining increased fracture strength as compared to the nonrestored groups ($p < 0.0001$). Inserting a piece of UHMW polyethylene fiber ribbon from buccal to lingual direction under resin composite restoration significantly increased fracture strength ($p < 0.0001$).

When the fracture sites were evaluated under 8× magnification, the teeth in group 1 were observed as crushed. Groups 2 and 3 showed mostly cuspal fracture. In group 4, 30% of the samples showed separation of the restoration from both buccal and lingual cusps. The failure occurred mostly between composite and the tooth structure. Group 5 showed 40% lingual cuspal fracture and in group 6, fracture was observed mostly between lingual cusp and composite restoration, and in 40% of the samples, lingual cusp fracture accompanied the fracture (Figure 5).

TABLE I. Mean Fracture Resistance (N) and the Standard Deviation for Each of the Six Experimental Conditions

Groups	Mean ± SD (N)
Group 1	1728 ± 274^{a}
Group 2	365 ± 32^{d}
Group 3	393 ± 28^{d}
Group 4	985 ± 152^{c}
Group 5	1055 ± 173^{c}
Group 6	1428 ± 175^{b}

$N = 10$ (number of the samples tested), SD, standard deviation. Similar letters indicate statistically similar values ($p > 0.05$).

DISCUSSION

Restoration of the teeth is an important final step of endodontic treatment. Reeh et al.[27] and Steele and Johnson[28] demonstrated that mere endodontic access in an otherwise intact tooth has only a minimal effect on the strength of the tooth. Steele and Johnson[28] reported that mean fracture strength for unrestored teeth with MOD preparation was 50% less than that of unaltered premolar teeth. The results of the present study showed that MOD preparation significantly reduced resistance to fracture in endodontically treated molar teeth (80%). The reduction of fracture strength among the two *in vitro* studies were found different possibly because of the variation among the cavity preparation techniques, testing conditions, or different operators. However, both studies indicated that reinforcement of the cavity with a restorative material is essential to support the remaining tooth structure and to regain some of the lost capacity.

Some studies have found that the use of bonded composite restorations will strengthen a tooth when compared with amalgam,[3,27] whereas others have reported that the difference is inconsequential.[29,30] When restoring with composite, many factors may effect the resistance of a tooth such as cavity dimension[31,32] or restorative system utilized.[33,34] With the use of composite restorations, it is well known that polymerization of resin is accompanied by shrinkage.[35] The stronger the adhesion achieved between the resin composite and dentin, the larger are the contraction stresses generated at the bonding interface. Feilzer et al.[12] evaluated the role of the bonded to unbonded surface area ratios on the development of polymerization stresses with CRs and described an *in vitro* model in which restorations with C-factor < 1 are the only ones likely to survive polymerization shrinkage stresses. Yoshikawa et al.[36] were the first to evaluate resin–dentin bond using the microtensile test in class I cavities and they found decreased bond strength for all adhesive systems tested under high C-factors. Other studies reported similar results regarding the negative effect of high C-factor on bond strength.[37–39]

Joynt et al.[29] suggested that the fracture resistance of CR restored premolar teeth with MOD cavity preparation may increase if an incremental method of resin placement and curing is used. This approach essentially reduces the total amount of shrinkage stresses through reduction in effective thickness and volume through use of sequential layering, although it creates additional interfaces that could be zones of weakness over extended periods of use. The high viscosity of a bonding agent may also provide a layer of substantial thickness that acts as a stress absorber[40] and flow of the composite may release contraction stresses.[41,42] In our previous study,[26] it was hypothesized that covering the surface with flowable composite or the addition of a ribbon of UHMW polyethylene fiber in the form of a leno weave before restoring teeth with resin composite would provide an increase in fracture strength. This was theorized on the idea that the presence of the UHMW polyethylene fiber network would create a change in the stress dynamics at the restoration/adhesive resin interface by providing multiple stress-paths along the fibers for redistribution of imposed load to intact portions of the teeth, and away from the bonded surfaces. This hypothesis was proved true and the results indicated that a ribbon of UHMW polyethylene fiber in the form of a leno weave use in combination with FR has significantly increased fracture strength of molar teeth with MOD cavity preparation. The network structure formed by the fiber reinforcement essentially serves as a series of tiny stitches across the bonded fractured surfaces assisting in further holding the surfaces together and preventing premature separation under imposed loads. It should be noted that the imposed compressive load used in the fracture test through Poisson's ratio effects puts a tensile force across the tooth in the transverse direction causing radially outward forces on the bonded segments and separative circumferential forces between bonded faces. In the absence of the fiber network, these forces would cause premature separation of the bonded surfaces as is seen in groups 3–5. It is emphasized that the base dentin material is intrinsically weaker in tension and the fiber network in the leno weave increases the capacity to withstand transverse tensile expansion. Confirming our previous study results, in the present study, inserting a piece of the fabric from buccal to lingual direction significantly increased fracture strength of endodontically treated molar teeth with MOD cavity preparation ($p < 0.0001$). Elastic modulus of polyethylene fiber with adhesive system was previously measured by Eskitascioglu et al.[25] The combined effect of the fiber modulus and the intrinsic fabric architecture, which has fibers oriented in multiple directions forwing an interwoven structure, allows for the forces to be distributed over a wider area, thereby decreasing stress levels. Further because of the interwoven nature of the fabric, the energy from the forces is itself absorbed and diffused to a large extent.

Meiers et al.[43] tested shear bond strength of composite to flat bovine enamel surfaces with four different fiber reinforcement materials. Although three of the four materials had no effect on shear bond strength, one of the tested materials (Connect, Kerr, Orange, Calif) improved shear bond strength. As a result, they concluded that the intrinsic properties of the fiber, especially the modulus, have a modifying effect on how the interfacial stresses are developed along the etched enamel/resin boundary. Haller et al.[44] reported a reduction of the bond strength to dentin of some adhesive systems when applied to 3D cavities in comparison with flat surfaces. In the present study, MOD cavities were used and the insertion of UHMW polyethylene fiber ribbon in leno weave form on the cavity surface increased fracture strength when compared to the restoration without the fiber reinforcement. While the results may be substantially different if flat surfaces were used with unidirectional fibers, the use of the essentially multiaxial structure of the leno weave allows for translation across configurations.

Farik et al.[45] reattached the original coronal fragment of traumatized fractured anterior teeth with a dentin bonding system and CR and reported that reattached teeth could withstand a second trauma to the same extent as intact teeth. In the present study, reattached teeth restored with CR and dentin bonding agent (group 4) exhibited higher fracture strength values than the unrestored and reattached teeth (group 3); however, this value was significantly lower than the intact teeth (group 1). On the other hand, there were no difference among the unrestored group either it has a reattached cusp or not (groups 2 and 3) ($p > 0.05$).

In this study, teeth that were reattached with the embedment of the UHMW polyethylene fiber ribbon (group 6) gave higher fracture strength. Polyethylene fibers are usually used for extensive adhesive restorations. They can easily adapt to the teeth surfaces[46] and this allows creation of splints or adhesive bridges.[21,47] Higher fracture strength values obtained for group 6 may be because of the adhesive property of the fiber reinforced composite restoration in successfully keeping the fractured segments bonded through mechanisms, as described earlier in this section.

In the present study, when the fracture sites observed under microscope, in 40% of the samples, lingual cusp fracture accompanied the fracture. This emphasizes the role of the leno weave UHMW polyethylene ribbon in serving to reinforce the restoration providing a bridging mechanism. Fracture under the compressive loading thus takes place at the weakest location within the overall system, and not necessarily at the location of the bonded joint. The introduction of new fracture surfaces emphasizes the efficiency of the restoration, as the bonded surfaces are now no longer the weakest elements. The fiber-reinforced composite through the specific orientation of fibers in the fabric and the higher properties within the layer essential act as stitches holding together the joint. As with adhesive bonding, the joint area, if prepared appropriately, is now stronger than the bulk due to constraint and redistribution, resulting in the joint surfaces now seeing lower levels of apparent stress. However, this also causes failure to now occur in the next weakest area. The dominance of cusp fracture is, thus, seen as the result of this transition in failure mechanisms. It is emphasized that although the transition in location and mechanism is due to the treatment used, the treatment itself precludes joint failure. Thus, it is important that care should be taken to completely understand transition mechanism so as to ensure against unintended failures.

This study was done in *in vitro* conditions and the test was performed 24 h after the restoration. The thermal, chemical, and physical stresses that the restoration could be subjected to over a long period *in vivo* may adversely affect the results, and therefore further investigation is necessary to predict *in vivo* behavior of this restoration types.

CONCLUSIONS

Within the limits of this study, it can be concluded that

1. MOD cavity preparation reduces fracture resistance of endodontically treated teeth.
2. Fracture resistance of rebonded fractured specimens were found similar to nonfractured samples, but significantly lower than the untreated original samples (group 1).
3. Reattachment of fractured fragments without further treatment (group 3) exhibited similar fracture strength with the unrestored samples (group 2) and attainment of only 22% of the fracture load of the original group 1 samples.
4. Inserting a leno weave configured ribbon of UHMW polyethylene fiber inside the cavity increases fracture strength of endodontically treated molar teeth with MOD cavity preparation and cuspal fracture. This enables attainment of 85% of the original level (group 1) of fracture load, which is substantially higher than that of even samples wherein low modulus liner was used between resin composite layers (group 5) that only attained 61% of the original, group 1, level.

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REFERENCES

1. Goerig AC, Mueninghoff LA. Management of the endodontically treated tooth. Part II: Technique. J Prosthet Dent 1983;49: 491–497.
2. Hudis SI, Goldstein GR. Restoration of endodontically treated teeth: A review of the literature. J Prosthet Dent 1986;55:33–38.
3. Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically treated teeth related to restorative techniques. J Dent Res 1989; 68:1540–1544.
4. Starr CB. Amalgam crown restorations for posterior pulpless teeth. J Prosthet Dent 1990;63:614–619.
5. Smales RJ, Hawthorne WS. Long-term survival of extensive amalgams and posterior crowns. J Dent 1997;25:225–227.
6. Trope M, Langer I, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated premolars. Endod Dent Traumatol 1986;2:35–38.
7. Hernandez R, Bader S, Boston D, Trope M. Resistance of fracture of endodontically treated premolars restored with new generation dentine bonding systems. Int Endod J 1994;27:281–284.
8. Farik B, Munksgaard EC, Kreiborg S, Andreasen JO. Adhesive bonding of fragmented anterior teeth. Endod Dent Traumatol 1998;14:119–123.
9. Farik B, Munksgaard EC, Suh BI, Andreasen JO, Kreiborg S. Adhesive bonding of fractured anterior teeth: Effect of wet technique and rewetting agent. Am J Dent 1998;11:251–253.
10. Farik B, Munksgaard EC. Fracture strength of intact and fragment-bonded teeth at various velocities of the applied force. Eur J Oral Sci 1999;107:70–73.
11. Davidson CL, de Gee AJ, Feilzer A. The competition between the composite-dentin bond strength and the polymerization contraction stress. J Dent Res 1984;63:1396–1369.
12. Feilzer AJ, De Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. J Dent Res 1987;66:1636–1639.
13. Kemp-Scholte CM, Davidson CL. Marginal sealing of curing contraction gaps in Class V composite resin restorations. J Dent Res 1988;67:841–845.
14. Davidson CL. Factors influencing the quality of composite restorations. In: Dondi dall'Orologia G, Prati C, editors. Theory and Practice Lining and Elasticity. Factors influencing the quality of composite restorations; theory and practice. Bologna International Symposium Nov 22–23, Ariesdue Srl-Carimate, Italy; 1996. p 87.
15. Kemp-Scholte CM, Davidson CL. Marginal integrity related to bond strength and strain capacity of composite resin restorative systems. J Prosthet Dent 1990;64:658–664.
16. Van Meerbeek B, Lambrechts P, Inokoshi S, Braem M, Vanherle G. Factors affecting adhesion to mineralized tissues. Oper Dent 1992;17(Suppl 5):111–124.
17. Belli S, Inokoshi S, Özer F, Pereira PNR, Ogata M, Tagami J. The effect of additional enamel etching and a flowable composite to the interfacial integrity of Class II adhesive composite restorations. Oper Dent 2001;26:70–75.
18. Valittu PK, Sevelius C. Resin-bonded glass fiber-reinforced composite fixed partial dentures: A clinical study. J Prosthet Dent 2000;84:413–418.
19. Edelhoff D, Spiekermann H, Yildirim M. Metal-free inlay-retained fixed partial dentures. Quintessence Int 2001;32:269–281.
20. Meiers JC, Duncan JP, Freilich MA, Goldberg AJ. Preimpregnated fiber-reinforced prostheses. Part II. Direct applications: Splints and fixed partial dentures. Quintessence Int 1998;29: 761–768.
21. Belli S, Özer F. A simple method for single anterior tooth replacement. J Adhes Dent 2000;2:67–70.
22. Meiers JC, Freilich MA. Fabricating a natural tooth pontic bridge using a pre-impregnated fiber reinforced composite technique. Oper Dent 2001;26:208–213.
23. Vallittu PK. The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture. J Prosthet Dent 1998;79:125–130.
24. Freilich MA, Meiers JC, Duncan JP, Goldberg AJ. Fiber Reinforced Composites in Clinical Dentistry. Chicago: Quintessence; 1999. p 9–21.
25. Eskitascioglu G, Belli S, Kalkan M. Evaluation of two post core systems using two different methods (fracture strength test and a finite elemental stress analysis). J Endod 2002;28:629–633.

26. Belli S, Erdemir A, Ozcopur M, Eskitascioglu G. The effect of fibre insertion on fracture resistance of root filled molar teeth with MOD preparations restored with composite. Int Endod J 2005;38:73–80.
27. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989;15:512–516.
28. Steele A, Johnson BR. In vitro fracture strength of endodontically treated molars. J Endod 1999;25:6–8.
29. Joynt RB, Wieczkowski G Jr, Klockowski R, Davis EL. Effects of composite restorations on resistance to cuspal fracture in posterior teeth. J Prosthet Dent 1987;57:431–435.
30. Allara FW Jr, Diefenderfer KE, Molinaro JD. Effect of three direct restorative materials on molar cuspal fracture resistance. Am J Dent 2004;17:228–232.
31. Mondelli J, Steagall L, Ishikiriama A, de Lima Navarro MF, Soares FB. Fracture strength of human teeth with cavity preparations. J Prosthet Dent 1980;43:518–521.
32. Purk JH, Eick JD, Roberts M, Chappell RP, Moore DL. Fracture strength of Class I versus Class II restored premolars tested at the marginal ridge. 2. Cavosurface bonding and cavosurface plus internal enamel bonding. Quintessence Int 1990;21:655–662.
33. Morin D, DeLong R, Douglas WH. Cusp reinforcement by the acid-etch technique. J Dent Res 1984;63:1075–1078.
34. Eakle WS. Increased fracture resistance of teeth: Comparison of five bonded composite resin systems. Quintessence Int 1986;17:17–20.
35. Bowen RL. Adhesive bonding of various materials to hard tooth tissues. VI. Forces developing in direct filling materials during hardening. JADA 1967;74:439–445.
36. Yoshikawa T, Sano H, Burrow MF, Tagami J, Pashley DH. Effects of dentin depth and cavity configuration on bond strength. J Dent Res 1999;78:898–905.
37. Armstrong SR, Keller JC, Boyer DB. The influence of water storage and C-factor on the dentin-resin composite microtensile bond strength and debond pathway utilizing a filled and unfilled adhesive resin. Dent Mater 2001;17:268–276.
38. Bouillaguet S, Ciucchi B, Jacoby T, Wataha JC, Pashley D. Bonding characteristics to dentin walls of class II cavities, in vitro. Dent Mater 2001;17:316–321.
39. Yoshikawa T, Burrow MF, Tagami J. The effects of bonding system and light curing method on reducing stress of different C-factor cavities. J Adhes Dent 2001;3:177–183.
40. Alhadainy HA, Abdalla AI. 2-year clinical evaluation of dentin bonding systems. Am J Dent 1996;9:77–79.
41. Takada A, Uno S, Sasaki T, Tanaka T, Kobayashi Y, Shimokobe H. The mechanical properties and marginal adaptation of light-cured composite restorations polymerized under a low light source intensity. Jpn J Cons Dent 1994;37:1090–1095.
42. Uno S, Takada A, Sasaki T, Tanaka T, Shimokobe H. Inner hardness and cavity adaptation of composite resin fillings polymerized at a low power light source. Jpn J Cons Dent 1994;37:888–892.
43. Meiers JC, Kazemi RB, Donadio M. The influence of fiber reinforcement of composites on shear bond strengths to enamel. J Prosthet Dent 2003;89:388–393.
44. Haller B, Klaiber B, Betz T, Dobersch S. Shear bond strength to dentin by simulation of three-dimensional Class V cavity configuration. Dent Mater 1991;7:206–210.
45. Farik B, Munksgaard EC, Andreasen JO. Impact strength of teeth restored by fragment-bonding. Endod Dent Traumatol 2000;16:151–153.
46. Rudo DN, Karbhari VM. Physical behaviors of fiber reinforcements as applied to tooth stabilization. Dent Clin North Am 1999;43:18–20.
47. Strassler HE. Aesthetic management of traumatized anterior teeth. Dent Clin North Am 1995;39:181–202.