Reinforcement effect of polyethylene fibre in root-filled teeth: comparison of two restoration techniques

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Abstract

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Aim To compare *in vitro* two different fibre placement techniques on reinforcement of root-filled molar teeth with mesio-occluso-distal (MOD) cavities.

Methodology Fifty sound extracted human mandibular molars were used ($n = 10$). Group 1 served as control. From group 2–5, endodontic access and standard MOD cavities were prepared. Following root canal treatment, group 2 was kept unrestored. In groups 3 and 4, the teeth were restored with composite resin (AP-X; Kuraray, Japan). A groove was prepared on occlusal surface of the finished restorations in group 4 from buccal to lingual direction. Polyethylene woven fibre (Ribbond; Seattle, WA, USA) was inserted in the groove in combination with flowable resin that was cured for 20 s and covered with composite resin. Cavity surfaces were covered with flowable resin in group 5, and polyethylene fibre was placed into the bed of resin in a buccal to lingual direction before the composite restoration was placed. All specimens were stored in 100% humidity at 37 °C for 24 h. Compressive loading of the teeth was performed by a universal testing machine at a cross-head speed of 0.5 mm min^{-1} until failure. The data were recorded in Newton and submitted to ANOVA and Tukey *post hoc* test.

Results The mean load necessary to fracture the samples in each group was: G1: 1671.57 ± 131.54^a; G2: 375.21 ± 34.30^b; G3: 749.47 ± 124.54^c; G4: 1224.36 ± 132.17^d; G5: 926.88 ± 118.28^e. Different superscript letters demonstrate significant difference between groups.

Conclusions Polyethylene fibre use over or under MOD composite restorations significantly increased fracture strength. However, when the fibre was placed on the occlusal surface of the restoration in buccal to lingual direction, significantly higher fracture resistance was observed.

Keywords: endodontically treated teeth, fracture resistance, polyethylene ribbon fibre.

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Introduction

Restoration of root-filled teeth is a critical final step for successful root canal treatment. Loss of dentine including anatomic structures such as cusps, ridges and arched roof of the pulp chamber may result in tooth tissue fracture after the final restoration. Therefore, intracoronal strengthening of teeth to protect them against fracture is important (Trope *et al.* 1986, Reeh *et al.* 1989), particularly in posterior teeth where stresses generated by forces of occlusion can lead to fracture of unprotected cusps (Wagnild & Mueller 2002). Traditionally, many root-filled teeth have been restored in conjunction with a post in the belief that they were reinforced, although there is little evidence to

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support this procedure (Gusy & Nicholls 1979). In fact, restoration of a tooth with a post has been shown by various authors to weaken the tooth rather than strengthen it (Trope *et al.* 1985, Lu 1987).

A number of new dentine-bonding systems have been developed recently and marketed. These bonding systems were introduced to increase the bond strength of composite resins to dentine, as well as to produce leak-free restorations. It is assumed that these bonding systems improve the adhesive capability and bonding strength of resins to tooth structure by promoting penetration, impregnation and entanglement of the coupling agents into dentinal substrates where they polymerize *in situ* and create zones of resin-reinforced dentine layers (Nakabayashi 1992). Hernandez *et al.* (1994) showed that resistance to fracture of root-filled premolar teeth with dentine bonding systems was increased significantly. However, contraction of an extensive composite restoration during polymerization is one of the factors affecting the outcome of a final restoration. A low viscosity intermediate resin used between the bonding agent and composite resin to act as an 'elastic buffer' has been previously suggested (Kemp-Scholte & Davidson 1990, Van Meerbeek *et al.* 1992). Use of flowable resin in root-filled molar teeth with MOD cavities did not increase fracture strength, on the other hand when a Leno Weave Ultra High Modulus (LWUHM) polyethylene fibre was inserted into the bed of flowable resin, fracture strength of teeth was increased (Belli *et al.* 2005). Use of an LWUHMW polyethylene fibre ribbon (Ribbond Inc., Seattle, WA, USA) in combination with bonding agent and flowable composite under composite restoration may act as a stress absorber because of its lower elastic modulus (Eskitascioglu *et al.* 2002); this elastic layer between the composite and dentine may have increased the fracture strength. Another explanation for this phenomenon may be because of the bonding ability of the material, the cusps might have been bonded together. If the bonding ability of the LWUHM polyethylene fibre was the reason for increased fracture strength, then an alternative insertion technique may allow a higher fracture strength to be achieved.

In the present study, an alternative technique, the effect of LWUHMW polyethylene fibre ribbon which was inserted over the occlusal surface was compared with the use of LWUHMW polyethylene fibre ribbon under the composite resin, a technique previously described by Belli *et al.* (2005). The effect of these techniques on cuspal fracture strength in root-filled molar teeth with MOD cavities was evaluated.

Materials and Methods

The materials used in this study and their composition are showed in Table 1. Fifty intact, noncarious, unrestored human mandibular second molar teeth, freshly extracted for periodontal reasons, with similar dimensions were selected. Any calculus and soft tissue deposits were removed from the teeth using a hand scaler (Gracey curette SG 17/18; Hu-Friedy, Chicago, IL, USA) and the teeth stored in physiological saline at +4 °C until required.

To minimize the influence of variations size and shape on the results, the teeth were classified according to their mesiodistal and buccolingual dimensions and randomly distributed into five 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 was used as control.

From groups 2–5: endodontic access cavities were prepared using a water-cooled diamond bur in a high-speed handpiece and the pulp tissue was removed with barbed broaches. A size 15 K-file was introduced into each canal until it could be seen at the apical foramen. The working length was determined by subtracting 1 mm from this length. The canals were prepared to a size 35 K-file at working length with a step-back technique. The coronal portion of each canal was enlarged with Gates Glidden burs (Mani Inc., Tochigi, Japan) size 1 through 3 in a slow-speed contra-angle handpiece. Two millilitres of 5.25% NaOCl was used as an irrigant solution during and after the biomechanical preparation. The canals were dried with absorbent paper points (Diadent Group International Inc., Chongju, Korea) and filled with gutta-percha (Diadent Group International Inc.) and AH Plus root canal sealer (Dentsply De Trey, Konstanz, Germany) using a cold lateral condensation technique. Excess root canal filling materials were removed with hot excavators at the canal orifice and the cavity cleaned. MOD cavities were 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 (CEJ), 1.5 mm at the lingual occlusal surface and 1.5 mm at the lingual CEJ. The teeth were then embedded in self-curing polymethyl methacrylate resin (Vertex, Dentimex Dental, Zeist, The Netherlands) to the level of the CEJ.

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Table 1 The materials used and their composition

Materials	Type	Manufacturer	Composition	Batch
SE Bond	Self-etch adhesive system	Kuraray Med Inc., Okayama, Japan	Primer: MDP, HEMA, hydrophilic dimethacrylate, *N,N*-diethanol *p*-toluidine, water. Adhesive resin: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, CQ, *N,N* diethanol *p*-toluidine, silanated colloidal silica	Primer 00433 A Adhesive 00593 A
Clearfil AP-X	Hybrid resin composite	Kuraray Med Inc., Okayama, Japan	Silanated barium glass, silanated silica, silanated colloidal silica, bisphenol a diglycidylmethacrylate, triethyleneglycol dimethacrylate, D,L-camphorquinone	42124
Protect liner F	Flowable composite	Kuraray Med Inc., Okayama, Japan	Silanated silica, silanated organic filler, bisphenol a diglycidylmethacrylate, triethyleneglycol dimethacrylate, mma-methacryloyl fluoride copolymer, D,L-camphorquinone	9925
Ribbond	Polyethylene fibre	Ribbond Inc., Seattle, WA, USA	Ultra-high molecular weight polyethylene	9532

Group 2

This group was not restored after an MOD cavity preparation.

Group 3

The cavities were cleaned and dried. After priming for 20 s (SE Primer; Kuraray Medical Inc., Okayama, Japan), cavity surfaces were gently dried. Clearfil SE Bond (Kuraray Medical Inc.) was applied to the cavity surfaces and cured for 20 s. The cavities were then restored with a resin composite (Clearfil AP-X; Kuraray Medical Inc.) using a bulk technique and cured for 40 s from the occlusal surface using a curing unit (Lunar Curing Light; Benlioglu Dental Inc., Ankara, Turkey) (Fig. 1). To standardize the curing distance, the tip of the polymerization unit was applied to the occlusal surface of the teeth. The intensity of light was at least 500 mW cm^{-2}. Verification of the unit light intensity output was checked with the digital read-out light meter available with the unit every 10 samples.

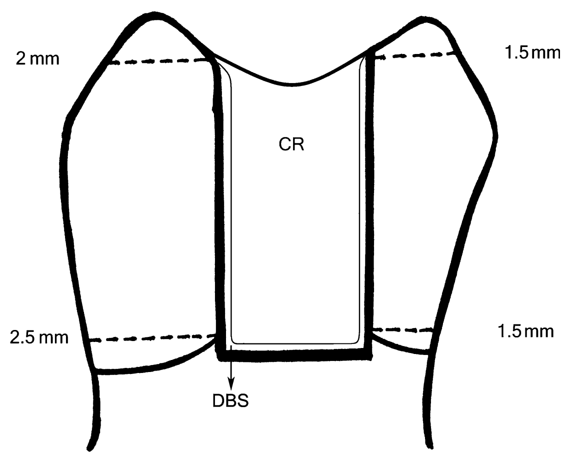

Figure 1 Schematic representation of restoration of teeth in group 3.

Group 4

The cavities of the teeth were restored with same dentine bonding system and composite resin as described as in group 3. After finishing the restoration, a groove 3-mm wide and 1-mm depth was prepared on the occlusal surface of the restorations between the cusp tips, from a buccal to lingual direction, with a high speed bur under water cooling. The end of the grooves was on the occlusal one-third of the buccal or lingual walls of the teeth. The grooves were rinsed and dried before flowable composite resin (FCR) (Protect Liner F; Kuraray Medical Inc.) was added to the floor of the groove cavities but not cured. A 3-mm wide LWUHMW polyethylene ribbon fibre (Ribbond Inc.) was cut using scissors. The fibre was first saturated with adhesive resin (Clearfil SE Bond; Kuraray Medical Inc.), the excess adhesive resin was removed with a hand instrument and then placed into the bed of un-cured FCR (Fig. 2). This combination was then cured for 20s from the occlusal surface using the same curing unit and the exposed fibre surface was covered with composite resin (Clearfil AP-X; Kuraray Medical Inc.) and cured for 40 s (Fig. 3).

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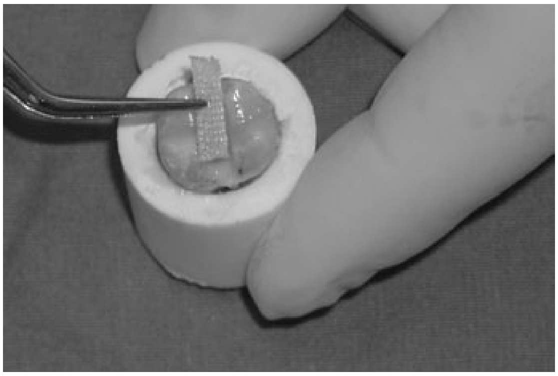

Figure 2 Insertion of 3-mm width polyethylene fibre to prepared groove in group 4.

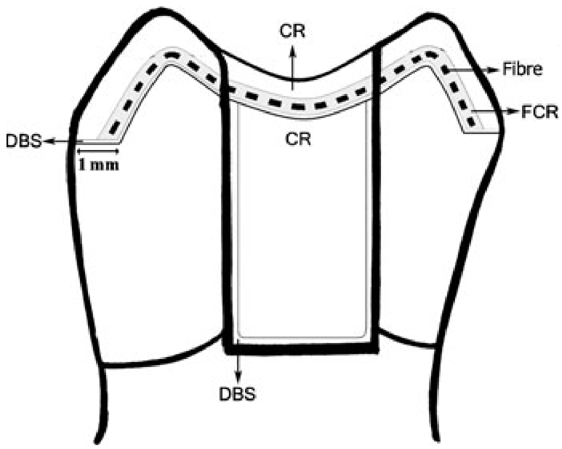

Figure 3 The schematic representation of teeth restored in group 4.

Group 5

After priming and bonding procedures, the cavity surfaces were coated with an FCR. Before curing, a piece of LWUHMW polyethylene fibre (8-mm long, 3-mm width) (Ribbond; Ribbond Inc.) was prepared as described in group 4 and embedded inside the FCR from the occlusal one-third of the buccal wall to the occlusal one-third of the lingual wall (Fig. 4). After curing for 20 s, the cavities were restored with composite as described above.

The restored teeth were stored in an incubator at 37 °C in 100% humidity for 24 h. The specimens were then placed into a Universal Testing Machine (Instron; Canton, MA, USA). A 5-mm diameter stainless steel bar was affixed to the upper stage of the Instron. The bar was parallel to the long axis of the teeth. The upper stage was positioned so that the bar was centred over

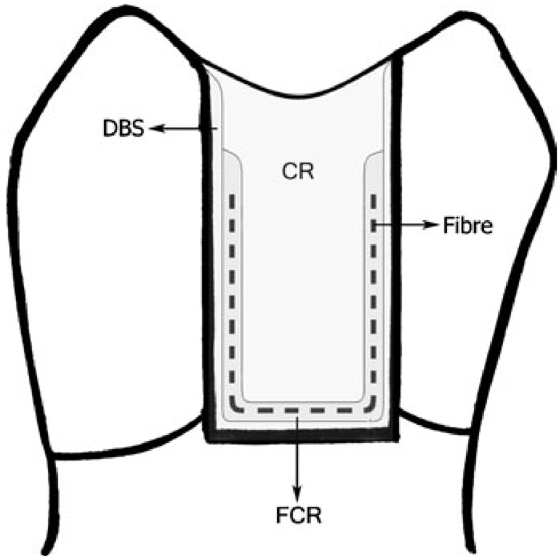

Figure 4 The schematic representation of teeth restored on group 5.

the teeth until the bar just contacted the occlusal surface of the restoration and buccal and lingual cusps of the teeth (Fig. 5). A vertical compressive force was applied at a crosshead speed of 0.5 mm min^{-1} and the force necessary to fracture each tooth was recorded as Newtons and the data were subjected to a one-way ANOVA and *post hoc* Tukey HSD test for the five experimental conditions.

After testing, the fracture surfaces were examined in a dissecting microscope (SZ-TP; Olympus, Tokyo, Japan) to determine the mode of fracture failure.

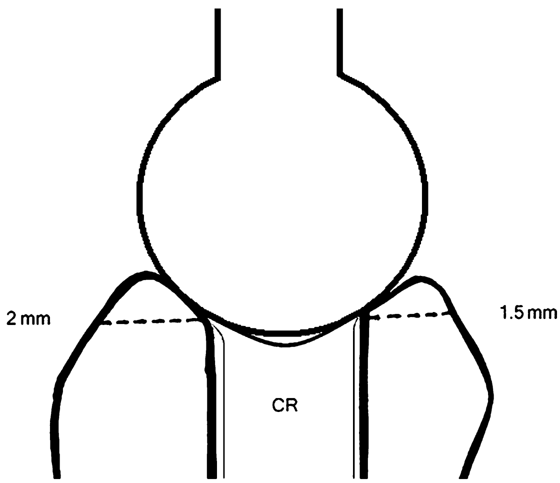

Figure 5 Vertical compressive force with a 5-mm stainless steel bar was applied at a crosshead speed of 0.5 mm min^{-1}.

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Table 2 Minimum, maximum and mean fracture resistance (*N*) and the SD for each of the five experimental conditions

Groups	Cavity	Restoration type	*n*	Minimum	Maximum	Mean ± SD
Group 1	Intact	Intact teeth	10	1523.80	1842.40	1671.57 ± 131.54[a]
Group 2	MOD	Nonrestored	10	340.70	430.20	375.21 ± 34.30[b]
Group 3	MOD	DBS + CR	10	575.40	878.00	749.47 ± 124.54[c]
Group 4	MOD	DBS + FCR + Fibre + CR (over composite restoration)	10	1050.80	1399.30	1224.36 ± 132.17[d]
Group 5	MOD	DBS + FCR + Fibre + CR (under composite restoration)	10	753.70	1079.10	926.88 ± 118.28[e]

DBS, dentine bonding system; CR, composite resin; FCR, flowable composite resin.
Different letters indicate statistically significant values ($P < 0.05$).

Results

The minimum, maximum and mean fracture resistance (*N*) and the SD for each of the five experimental conditions are presented in Table 2.

One-way ANOVA indicated that overall difference in statistical significance between the groups was found at the 0.05 level and Tukey *post hoc* tests indicated that fracture strength of group 1 was significantly higher than the other groups ($P < 0.05$). Restoring teeth with resin composite (group 3) increased fracture strength when compared with the nonrestored group (group 2) ($P < 0.05$). Inserting a piece of LWUHMW polyethylene fibre from buccal to lingual direction under the resin composite restoration (group 5) significantly increased fracture strength of molar teeth with MOD cavities when compared with the group 3, which was restored with dentine bonding system and composite resin ($P < 0.05$). In group 4, the preparation of a groove in a bucco-lingual direction after finishing the restoration and inserting a polyethylene fibre provided significantly higher fracture strength than group 5 restored with the use of the fibre under the restoration (group 5) ($P < 0.05$).

When the fracture modes were evaluated, both samples demonstrated cuspal fracture except groups 1 and 4. The fracture lines were generally on or just near CEJ. In group 4, cohesive fracture on composite and FCR was observed. The fibre inserted on occlusal surface prevented the separation of the fractured structures. In group 5, cohesive fracture inside the fibre-FCR combination and expose of the fibre was observed after the fracture of the cusps was generally observed.

Discussion

The purpose of a restorative material is not only to restore the decayed or defective tooth and provide an effective seal between the restoration and the tooth, but also to strengthen the tooth. In the present study, the strength of the teeth was significantly reduced after cavity preparation, as shown in previous studies (Mondelli *et al.* 1980, Gelb *et al.* 1986, Joynt *et al.* 1987, El-Sherif *et al.* 1988). On the other hand, it is interesting to note that in the studies of Re *et al.* (1981) and Blaser *et al.* (1983) there was no significant difference between fracture resistance of intact teeth and the teeth that were prepared but unrestored. Extension of a cavity preparation may reduce fracture strength of a tooth. The brittleness of root-filled teeth has been discussed previously (Carter *et al.* 1983, Sedgley & Messer 1992). Recent reports have indicated that the fracture strength of root-filled teeth was reduced because of tooth structure loss (Mondelli *et al.* 1980, Gelb *et al.* 1986, Joynt *et al.* 1987, El-Sherif *et al.* 1988, Jagadish & Yogesh 1990, Bader *et al.* 2004). An extensive MOD preparation in a root-filled tooth may cause cuspal fracture if the tooth is not restored (Gelb *et al.* 1986, Joynt *et al.* 1987, Reeh *et al.* 1989, Pilo *et al.* 1998). The results of the present study also showed that restoration of a root-filled tooth is important to achieve an increased resistance to fracture.

Individual variations in morphology amongst the teeth including angulation of cuspal inclines, thickness of enamel, inherent weaknesses, variation amongst the size of teeth, and variations in the level of contact of the metal rods with the cuspal inclines during the fracture were amongst many factors that may have contributed to the large SDs. However, according to Jagadish & Yogesh (1990), if a standardized tooth model had been available, the SDs may have been reduced. Many differences exist between fractures occurring clinically and those induced by a testing machine. Forces generated intraorally during function vary in magnitude, speed of application and direction, whereas the forces applied to the teeth in this study were at a constant direction and speed, and they increased continually until the fracture occurred. (Jagadish & Yogesh 1990). The results indicate that the use of a fibre under or over the final composite restoration significantly increased fracture strength. However, the

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clinical conditions and complexity of forces generated intraoral restoration techniques described in this study must be evaluated further *in vivo*.

Industrial applications of composite and laminated structures with polymers provided dental researchers with bondable, ultrahigh tensile strength, fracture tough, aesthetic, extremely manageable reinforcement materials that have the potential to be applied to dental restoration (Rudo & Karbhari 1999). Since 1991, Ribbond bondable reinforcement ribbon has been used successfully for a variety of clinical techniques (Strassler & Serio 1997, Rudo & Karbhari 1999, Eskitascioglu *et al.* 2004, Karaman *et al.* 2002). A study by Ramos *et al.* (1996) demonstrated that polymethylmethacrylate test bars containing Ribbond gave a significant increase in fracture strength over nonreinforced test bars. In addition to the increased fracture resistance to crack propagation, the reinforced bars remained in one piece throughout the compression loading cycle.

In an *in vitro* study (Samadzadeh *et al.* 1997), Ribbond-reinforced, bis GMA-based, three-unit fixed bridges demonstrated significantly greater fracture loads than non-Ribbond-reinforced samples. Physically, the open geometry of the tightly woven leno weave allows for complete infusion and 'wet-out' of the fibres by the resin. Chemically, the LWUHMW polyethylene fibre is converted from a hydrophobic material to a hydrophilic material by being subjected to cold gas plasma treatment. Miller & Schwartz (1997) demonstrated that the effect of plasma treatment on the LWUHMW polyethylene fibres is not only an increase in wettability, but also the creation of a chemical bond between the LWUHMW polyethylene fibre and the resin.

According to Rudo & Karbhari (1999), the successful performance of the LWUHMW polyethylene fibre is because of the properties of the fibre itself, the degree of chemical bonding between the resin and the fibre and the effect of the leno weave with regard to crack resistance and deflection as well as resistance to shifting within the resin matrix.

The fibre, as mentioned earlier, exhibits the structural aesthetics and handling characteristics necessary for a dental fibre composite material. The plasma treatment ensures an adequate bond to the resin matrix. The tightly woven leno weave unique to Ribbond provides a fixed position between the warp (lengthwise) and weft (crosswise) fibres. The weave is open enough to allow for efficient infusion and wetting of the resin on the fibres and ease of manageability (Rudo & Karbhari 1999). In a previous study (Belli *et al.* 2005), Ribbond fibre used under filled composite resin in combination with flowable resin increased the fracture strength in root-filled teeth with MOD preparations. It was assumed that polyethylene fibre had stress-modifying effect along the restoration and dentine interface. The other possible explanation of the results was that the bonding ability of fibre in combination with resin might have increased the fracture strength of the tooth by keeping both cusps together. In the present study, during the preparation of the samples, composite restorations were inserted in bulk and cured from the occlusal surface for 40 s although incremental composite curings are favoured in clinical conditions. Using the bulk technique, the effect of restoration placement was eliminated. On the other hand, in groups 4 and 5, the cavities were lined with an FCR and this layer created an additional increment. Furthermore, the composite restorations received an additional light curing cycle from the occlusal surface in group 4 although the total curing time period was 40 s in other groups. As the aim of this study was to assess the most appropriate way of using fibre in root-filled teeth, these other factors were disregarded and only the different techniques were evaluated.

In a previous study, it was found that flowable composite had no effect on fracture strength of root-filled teeth with MOD cavities (Belli *et al.* 2005). On the other hand, when fibre was embedded into a bed of flowable resin, the fracture strength was increased (Belli *et al.* 2005). In the present study, an alternative fibre insertion technique was evaluated. In this technique, the natural cusps were protected, a groove was prepared from a buccal to lingual direction and the fibre was inserted in this groove and covered with composite resin. Extension of the fibre ends through the occlusal one-third of the buccal or lingual walls allowed the fibre to keep the cusps together and the additional bonding ability of the material provided a greater fracture resistance in root-filled teeth with MOD cavities when compared with the previously described technique. However, further *in vitro* and *in vivo* investigations are needed before these materials can be recommended for routine use in clinical practice.

Conclusions

1. Composite resin restoration increased the fracture strength of the root-filled teeth with MOD preparations.
2. Use of polyethylene fibre before or after the restoration significantly increased the fracture strength.

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3. When the fibre was placed on the occlusal surface of the restoration from a buccal to lingual direction, significantly higher fracture resistance was observed.

References

Bader JD, Shugars DA, Martin JA (2004) Risk indicators for posterior tooth fracture. *Journal of the American Dental Association* **135**, 883–92.

Belli S, Erdemir A, Ozcopur M, Eskitascioglu G (2005) The effect of fibre insertion on fracture resistance of root filled molar teeth with MOD preparations restored with composite. *International Endodontic Journal* **38**, 73–80.

Blaser PK, Lund MR, Cochran MA, Potter RH (1983) Effects of designs of class 2 preparations on resistance of teeth to fracture. *Operative Dentistry* **8**, 6–10.

Carter JM, Sorensen SE, Johnson RR, Teitelbaum RL, Levine MS (1983) Punch shear testing of extracted vital and endodontically treated teeth. *Journal of Biomechanics* **16**, 841–8.

El-Sherif MH, Halhoul MN, Kamar AA, Nour el-Din A (1988) Fracture strength of premolars with class 2 silver amalgam restorations. *Operative Dentistry* **13**, 50–3.

Eskitascioglu G, Belli S, Kalkan M (2002) Evaluation of two post core systems using two different methods (Fracture strength test and a finite elemental stress analysis study). *Journal of Endodontics* **28**, 629–33.

Eskitascioglu G, Eskitascioglu A, Belli S (2004) Use of polyethylene ribbon to create a provisional fixed partial denture after immediate implant placement: a clinical report. *Journal of Prosthetic Dentistry* **91**, 11–4.

Gelb MN, Barouch E, Simonsen RJ (1986) Resistance to cusp fracture in class II prepared and restored premolars. *Journal of Prosthetic Dentistry* **55**, 184–5.

Gusy GE, Nicholls JI (1979) In vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. *Journal of Prosthetic Dentistry* **42**, 39–44.

Hernandez R, Bader S, Boston D, Trope M (1994) Resistance to fracture of endodontically treated premolars restored with new generation dentine bonding systems. *International Endodontic Journal* **27**, 281–4.

Jagadish S, Yogesh BG (1990) Fracture resistance of teeth with class 2 silver amalgam, posterior composite and glass cermet restorations. *Operative Dentistry* **15**, 42–7.

Joynt RB, Wieczkowski Jr G, Klockowski R, Davis EL (1987) Effects of composite restorations on resistance to cuspal fracture in posterior teeth. *Journal of Prosthetic Dentistry* **57**, 431–5.

Karaman AI, Kir N, Belli S (2002) Four applications of reinforced polyethylene fiber material in orthodontic practice. *American Journal of Orthodontics and Dentofacial Orthopedics* **121**, 650–4.

Kemp-Scholte CM, Davidson CL (1990) Marginal integrity related to bond strength and strain capacity of composite resin restorative systems. *Journal of Prosthetic Dentistry* **64**, 658–64.

Lu YC (1987) Comparisons of the fractures of pulpless teeth. *Clinical Dental Journal* **6**, 26–31.

Miller A, Schwartz P (1997) Effects of oven aging on plasma treated ultra high strength polyethylene. *Plasmas and Polymers* **2**, 115–32.

Mondelli J, Steagall L, Ishikiriama A, de Lima Navarro MF, Soares FB (1980) Fracture strength of human teeth with cavity preparations. *Journal of Prosthetic Dentistry* **43**, 419–22.

Nakabayashi N (1992) Resin reinforced dentin due to infiltration of monomers into dentin at the adhesive interface. *International Journal Dental Materials* **1**, 78–81.

Pilo R, Brosh T, Chweidan H (1998) Cusp reinforcement by bonding of amalgam restorations. *Journal of Dentistry* **26**, 467–72.

Ramos V, Runyan DA, Christensen LC (1996) The effect of plasma-treated polyethylene fiber on the fracture strength of polymethyl methacrylate. *Journal of Prosthetic Dentistry* **76**, 94–6.

Re GJ, Draheim RN, Norling BK (1981) Fracture resistance of mandibular molars with occlusal class I amalgam preparations. *Journal of the American Dental Association* **103**, 580–3.

Reeh ES, Douglass WH, Messar HH (1989) Stiffness of endodontically treated teeth related to restorative techniques. *Journal of Dental Research* **68**, 1540–4.

Rudo DN, Karbhari VM (1999) Physical behaviors of fiber reinforcement as applied to tooth stabilization. *Dental Clinics of North America* **43**, 7–35.

Samadzadeh A, Kugel G, Hurley E, Aboushala A (1997) Fracture strengths of provisional restorations reinforced with plasma-treated woven polyethylene fiber. *Journal of Prosthetic Dentistry* **78**, 447–50.

Sedgley CM, Messer HH (1992) Are endodontically treated teeth more brittle? *Journal of Endodontics* **18,** 332–5.

Strassler HE, Serio FG (1997) Stabilization of the natural dentition in periodontal cases using adhesive restorative materials. *Periodontal Insights* **4**, 4–10.

Trope M, Maltz DO, Tronstad L (1985) Resistance to fracture of restored endodontically treated teeth. *Endodontics and Dental Traumatology* **1**, 108–11.

Trope M, Langer I, Maltz DO, Tronstad L (1986) Resistance to fracture of restored endodontically treated premolars. *Endodontics and Dental Traumatology* **2**, 35–8.

Van Meerbeek B, Lambrechts P, Inokoshi S, Braem M, Vanherle G (1992) Factors affecting adhesion to mineralized tissues. *Operative Dentistry* **17**, 111–24.

Wagnild GW, Mueller KI (2002) Restoration of the endodontically treated tooth. In: Cohen S, Burns RC, eds. *Pathways of the Pulp*, 8th edn. St Louis, MO, USA: Mosby Inc., pp. 765–95.

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