International Endodontic Journal

doi:10.1111/j.1365-2591.2010.01843.x

Influence of several fibre-reinforced composite restoration techniques on cusp movement and fracture strength of molar teeth

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Abstract

Akman S, Akman M, Eskitascioglu G, Belli S. Influence of several fibre-reinforced composite restoration techniques on cusp movement and fracture strength of molar teeth. *International Endodontic Journal*, **44**, 407–415, 2011.

Aim To compare mean cusp movement in molar teeth with endodontic access and mesial-occlusal-distal (MOD) cavities before and after restoration with several fibre-reinforced composite restoration techniques under loading and to evaluate the effect of restoration technique on fracture strength.

Methodology Reference points were marked at the mesial cusp ridges of extracted human mandibular molar teeth. Digital images were taken under loading (300 N) using a stereomicroscope (Leica MZ16A; Wetzlar, Germany). Three-dimensional (3D) distances between the reference points were recorded (Leica, Stereo-Explorer, 2.1) as controls. Standard MOD cavities were prepared and restored as follows (n = 10), group 1: composite restoration (Clearfil AP-X; Kuraray, Tokyo, Japan); group 2: cavity lined with polyethylene fibre (Ribbond, Ribbond Inc., Seattle, WA, USA) in combination with flowable resin (Protect-Liner F; Kuraray, Tokyo, Japan) before composite restoration; group 3: polyethylene fibre inserted on occlusal surface of the tooth from buccal to lingual after finishing the composite restoration; group 4: missing walls were restored with composite resin and inner surfaces of the axial walls were then reinforced with polyethylene fibre placed circumferentially before the composite restoration. The restored teeth were re-loaded, digital images were re-taken and the 3D distance between the reference points was recorded in μm. Comparisons of the restoration techniques, the effectiveness of restoration for each group were analysed statistically (Kruskall–Wallis, paired-samples t-test). The teeth were then loaded until failure (5 mm min^{-1}), the data were recorded (N) and analysed statistically (Kruskall–Wallis test).

Results A significant difference occurred amongst the groups in terms of cusp movement (P = 0.018). All the groups revealed a decrease in inter-cuspal width when compared to their initial records. The mean values of these decreases were as follows: group 1 17.6 (P = 0.003), group 2 6.7 (not sig), group 3 6.6 (not sig) and group 4 0.85 (not sig) μm. No significant difference was found amongst the fracture strength values (P = 0.22). In group 1, 90% of the fractures were non-restorable, whereas in group 3 100% of the fractures were restorable.

Conclusions Regardless of restoration technique, fibre reinforcement of composite restorations decreased cusp movement in molar teeth with MOD and endodontic access cavities but did not affect fracture strength.

Keywords: cuspal deflection, cuspal movement, fibre-reinforced composites, endodontically treated teeth, loading, topographical mesurement.

Received 8 July 2010; accepted 21 November 2010

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Introduction

The quality and longevity of restorations in endodontically treated teeth play an important role in the outcome (Ng *et al.* 2008), and they must be considered as a critical final step for successful root canal treatment. Previous caries, pre-existing restorations or endodontic procedures may lead to loss of substantial tooth structure and make restoration procedures more complicated. Cast coverage techniques (Goerig & Mueninghoff 1983), complex amalgam restorations (Smales & Hawthorne 1997), indirect cast restorations (Reeh *et al.* 1989a) and composite restorations (Hurmuzlu *et al.* 2003) have been used in the past for final restorations. The preservation of tooth structure under occlusal loading is important and, unlike amalgam, bonded composite restorations usually strengthen the tooth (Reeh *et al.* 1989a). However, polymerization shrinkage remains a problem in extensive direct composite restorations (De Gee *et al.* 1993).

Polymerization shrinkage of resin-based composites and the associated stress generated in tooth tissues (Davidson & Feilzer 1997) manifest clinically as cuspal deflection (Causton *et al.* 1985, Davidson & Feilzer 1997). Cuspal deflection is a common biomechanical phenomenon observed in teeth restored with composites as a result of interactions between the polymerization shrinkage stress of the composite and the compliance of the cavity wall (Lee *et al.* 2007). Cusp deflection may cause post-operative pain and sensitivity (Bausch *et al.* 1982), may affect the tooth–restoration interface and lead to bacterial microleakage and secondary caries (Kemp-Scholte & Davidson 1988), may cause pulpal inflammation or necrosis (Lutz *et al.* 1991) and may eventually lead to enamel or tooth fracture (Marzouk & Ross 1989). Panitvisai & Messer (1995) reported that cuspal deflection increased with increased cavity preparation following endodontic access.

Modifications that reduce or eliminate the interfacial stress concentrations in extensive composite restorations may reduce cuspal deflection. The higher modulus of elasticity and lower flexural modulus of polyethylene fibre have a modifying effect on the interfacial stresses developed along the etched enamel/resin boundary (Meiers *et al.* 2003). Different polyethylene fibre-reinforced composite restoration techniques have been introduced including lining the fibre under the composite resin (Belli *et al.* 2005a; 2006a,b) or over the finished composite restoration by preparing a groove (Belli *et al.* 2006b). Deliperi *et al.* (2005) introduced a new technique to eliminate the use of posts. In this technique, the missing walls were first restored with composite resin, and polyethylene fibre was used inside the axial walls circumferentially to reinforce the restoration. The clinical success of this restoration was also demonstrated by Deliperi (2008).

The remaining tooth structure was reported to be saved when polyethylene fibre reinforcement and fibre-reinforced restorations failed in a restorable manner compared to restorations without polyethylene fibre (Sengun *et al.* 2008). This outcome is explained by the stress modifying effect of the composite–polyethylene fibre combination (Eskitascioglu *et al.* 2002, Belli *et al.* 2005a). Finite elemental analysis has also shown that fibre-reinforced restorations have a stress reducing effect in the remaining tooth structure (Eskitascioglu *et al.* 2002, Belli & Eskitascioglu 2008).

The effects of polyethylene fibre-reinforced restorations on the fracture strength of molar teeth with a MOD cavity (Belli *et al.* 2005b), the microtensile bond strength to dentine (Belli *et al.* 2006a) and the microleakage in cavities with a high C-factor (Belli *et al.* 2007) have been evaluated previously. However, the possible effects of these fibre-reinforced restorations on cuspal deflection or remaining tooth structure and the relationship between cusp movement and fracture strength have not been studied. Hence, the objectives of this study were to compare the mean cusp movement in molar teeth with endodontic access and MOD cavities before and after restoration with different fibre-reinforced composite restoration techniques under loading. The study also aimed to evaluate the effect of restoration technique on fracture strength using a 3D topographical measurement system. The null hypothesis was that fibre reinforcement during composite restoration of an MOD cavity with endodontic access would have no effect on cusp movement or fracture strength.

Materials and methods

Forty-two intact, un-restored, non-carious human mandibular first molar teeth that were stored in sterile water from the time of extraction were selected. The teeth were kept moist throughout the experiment at room temperature (23 ± 1 °C), except when aspects of the experimental procedure required isolation from moisture. Anatomical crowns were similar in dimension, measuring 12.1 ± 0.8 mm mesiodistally and 10 ± 0.6 mm buccolingually at the level of the cementum–enamel junction (CEJ). The coronal height was limited to 6.8 ± 0.3 mm. Calculus and soft tissue remnants were removed using a hand scaler (Gracey Curetta SG 17/18; Hu-Friedy, Chicago, IL, USA). To reproduce the periodontal ligament and alveolar bone support, root surfaces were dipped into melted wax up to 1 mm below the CEJ using a unit for the wax dipping technique (Ceradip, Bego, Germany), which resulted in a 0.3-mm-thick wax layer. The teeth were then embedded vertically in self-curing polymethyl methacrylate resin (Vertex, Dentimex Dental, Zeist, Netherlands) to a level 1.0 mm apical to the CEJ. Next, the teeth were removed from the resin blocks and the wax was eliminated. The space formed between the root surface and the polymethyl methacrylate resin was filled with silicone paste (Dow Corning 3140 RTV coating; Dow Corning Corp., Midland, MI, USA) to simulate the periodontal ligament (Fonseca *et al.* 2007).

The load required to cause a fracture was determined to ensure an adequate safety range for the maximum load used; two teeth were used for this purpose. An extensive MOD cavity and endodontic access cavity were prepared under water cooling using a high-speed turbine with a diamond bur. The teeth were positioned in a universal testing machine (Instron, Canton, MA, USA) so that the occlusal inclines of the facial and lingual cusps of the teeth were simultaneously contacted by a steel sphere with a 4-mm-diameter ball. The samples were then subjected to a ramped load until fracture occurred.

Fracture occurred at a load of 380–400 N, and it was concluded that loads up to 300 N could be applied safely. Reference points were marked at the mesial cusp ridges, and the teeth were fixed in a manual test stand that included a digital dynamometer (Sauter FK 1K; Sauter GmbH, Basel, Switzerland). The test stand was positioned under a stereo microscope (Leica MZ16A; Leica Microsystems GmbH, Wetzlar, Germany). Digital images were taken using a digital camera (Leica ICD 3, Leica Microsystems GmbH, Wetzlar, Germany) at 50× magnification under loading (300 N), and the width between the reference points for each tooth was recorded in micrometres (μm) using software (Stereo-Explorer, 2.1; Leica Microsystems GmbH, Wetzlar, Germany) (Fig. 1a).

Each tooth was prepared with an MOD cavity and endodontic access. The thickness of the buccal wall of the teeth was 3.5 ± 0.5 mm at the CEJ and 3 ± 0.3 mm at the lingual CEJ and the proximal boxes were 1 mm above the CEJ. Endodontic access cavities were prepared using a diamond bur-fitted (M&A Diatech, Heerbrugg, Switzerland) high-speed hand-piece under water cooling. The root canal orifices were sealed with Super Bond C&B (Sun Medical, Tokyo, Japan). The teeth were randomly divided into four groups and numbered, and the MOD cavities were then restored using the following techniques (n = 10):

- Group 1: The cavity was dried and primed for 20 s (Clearfil SE Primer; Kuraray Inc., Tokyo, Japan). Clearfil SE Bond (Kuraray Inc., Tokyo, Japan) was applied to the cavity surfaces and cured for 10 s using a light-curing unit with a minimum intensity of 700 mW cm^{-2} (Bluephase, Ivoclar Vivadent, MV, Schaan, Liechtenstein). The cavity was then restored with a composite resin (Clearfil AP-X; Kuraray Inc.) using an incremental technique. Each increment was cured from the occlusal side for 40 s.

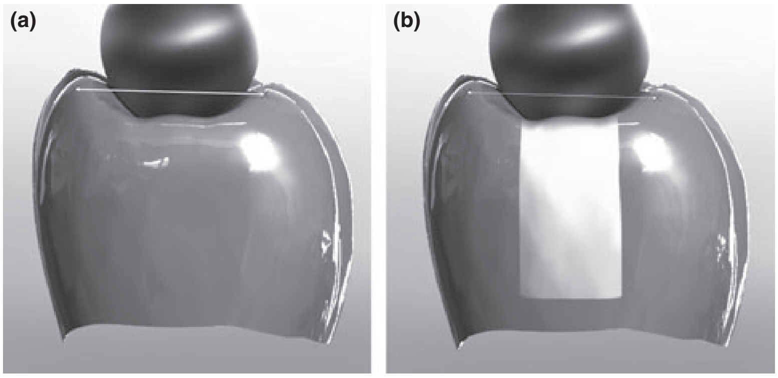

Figure 1 Schematic representation of the measurement of inter-cuspal width. The distance between the reference points at the initial position under loading (a) was measured; the distance between the reference points after endodontic access, MOD cavity preparation and restoration under loading (b) was then measured. The difference between the initial width (a) and final width (b) was recorded in μm.

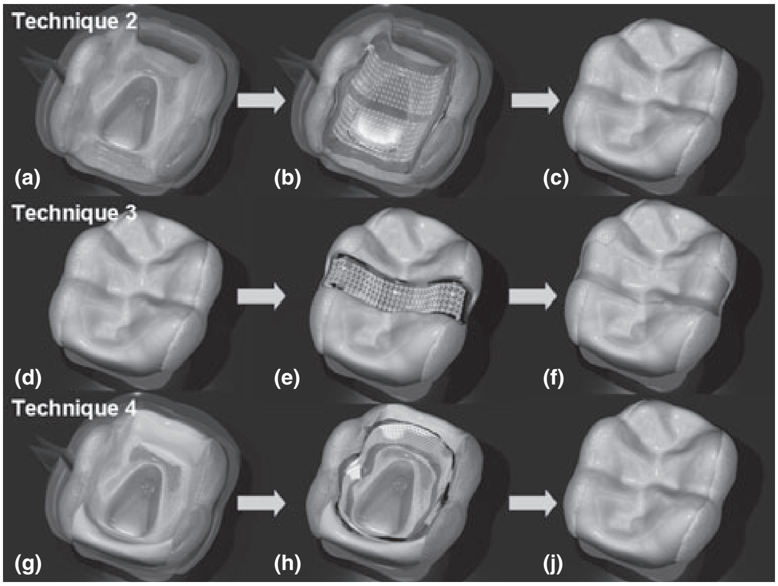

Figure 2 Schematic representation of the restoration techniques. (a–c) Polyethylene fibre in combination with flowable resin was lined under the composite resin restoration; (d–f) polyethylene fibre was inserted in a groove prepared at the occlusal surface of the finished composite resin restoration; (g–j) polyethylene fibre was inserted circumferentially inside the cavity after creating approximal boxes with composite resin.

- Group 2: After the bonding procedures as described in technique 1 (Fig. 2a), the cavity was lined with a flowable resin (Protect Liner F; Kuraray Inc., Tokyo, Japan) at a thickness of 0.5–1 mm. Two pieces of 3-mm-wide polyethylene fibre (Ribbond THM; Ribbond Inc., Seattle WA, USA) were cut after determining the required length, using aluminium foil, and then saturated with adhesive resin (Clearfil SE Bond) for two minutes. Excess resin was removed from the fibre surface using a hand instrument parallel to the direction of the fibre and embedded into the bed of flowable resin according to a protocol previously described by Belli *et al.* (2005a, 2006a,b) (Fig. 2b). The fibre-reinforced flowable resin was cured for 20 s, and the cavity was then restored with composite resin using the incremental technique. Each increment was cured from the occlusal side for 40 s (Fig. 2c).
- Group 3: The cavity was restored with composite resin using the incremental technique after bonding procedures, and each increment was cured from the occlusal side for 40 s (Fig. 2d). A groove (3 mm wide and 1 mm deep) was prepared from the buccal to the lingual direction beginning at the occlusal 1/3 of the buccal wall and ending at the occlusal 1/3 of the lingual wall. The groove was lined with flowable resin and a 2-mm-wide, pre-wetted polyethylene fibre was embedded into the bed of flowable resin and cured for 20 s (Fig. 2e). The groove was then restored with the same resin composite material and cured for 40 s (Fig. 2f). (Belli et al. 2006b).
- Group 4: After bonding procedures, mesial and distal composite resin walls were created using a matrix band and cured for 40 s (Fig. 2g). The inner surfaces of the axial walls were then lined with flowable resin, and a 3-mm-wide, pre-wetted polyethylene fibre was embedded into the bed of flowable resin circumferentially following a protocol previously described by Deliperi (2008)(Fig. 2h). After curing for 20 s, the cavity was restored with composite resin. Each increment was cured from the occlusal side for 40 s (Fig. 2j).

After finishing and polishing procedures, the restored teeth were positioned in a universal testing machine so that the occlusal inclines of the facial and lingual cusps of the teeth made contact simultaneously with the same 4-mm-diameter steel sphere. The restoration was re-finished when a problem with contact because of composite restoration occurred. The samples were re-loaded, digital images were re-taken and the width between the reference points was recorded three dimensionally (Fig. 1b). The difference between the initial width and the final width of the reference points was recorded as cusp movement in μm.

Finally, the teeth were positioned in the universal testing machine as described earlier and loaded until

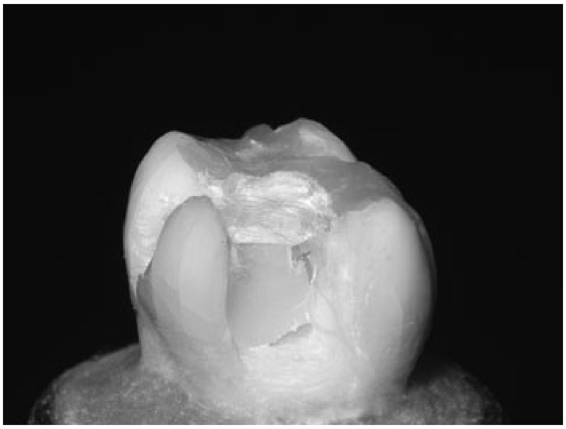

Figure 3 A composite resin fracture that is considered as restorable (type 1) in a specimen treated using technique 3.

failure (5 mm/min^{-1}). The load necessary to cause the fracture of each sample was recorded in Newtons (N).

The fracture pattern of each sample was classified as follows:

- Type 1: Cusp or composite resin fracture above the CEJ considered to be restorable (Fig. 3).
- Type 2: A vertical fracture at one or two cusps that did not extend into the root and was considered to be restorable.
- Type 3: A vertical fracture at one or two cusps below the CEJ extending into the root and was considered to be non-restorable.
- Type 4: Vertical longitudinal fractures involving the crown that extended into the root or bifurcation and was non-restorable (Fig. 4).

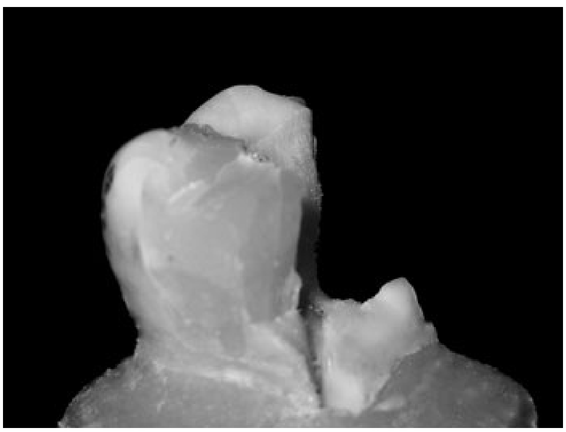

Figure 4 Vertical fracture at one cusp below the cementum–enamel junction that extends into the root (type 3, non-restorable failure pattern) in a composite resin-restored specimen.

Statistical analysis

Comparisons of the restoration techniques were analysed using a Kruskall–Wallis test. The similarity of cusp movement for each group before and after restoration was analysed using paired-samples *t*-tests. The fracture strength values were analysed statistically using a Kruskall–Wallis test.

Results

Table 1 shows the mean changes of inter-cuspal width for each group and the mean and standard deviation (SD) values of load at fracture. A significant difference was found amongst the groups in terms of cusp movement ($P = 0.018$). All the groups revealed a decrease in inter-cuspal width when compared to their initial records. This decrease was significant only for the group restored with direct composite restoration (group 1) ($P = 0.003$), which was restored without fibre reinforcement. No significant difference was found amongst the fracture strength values ($P = 0.22$).

Table 2 shows the fracture patterns of the samples after failure. Teeth in group 3 had a 100% restorable fracture pattern whilst the teeth in group 2 had an 80% restorable fracture pattern (Fig. 3). Teeth in group 1 had a 90% non-restorable fracture pattern (Fig. 4).

Discussion

Several methods have been used previously to measure cusp deflection/movement, including photography (Segura & Donly 1993), microscopy (Suliman *et al.* 1994), strain gauges (McCullock & Smith 1986), interferometers (Suliman *et al.* 2003), linear variable differential transformers (Meredith & Setchell 1997) and a novel non-contact technique (Martin *et al.* 1999). In this laboratory study, a 3D topographical measurement system was used. The system consists of an integrated stereo camera, software and a display system. The digital camera has two independent RGB sensors that create stereo pairs, and the software automatically creates 3D data records on the monitor using two-dimensional stereomicroscope photographs. The most important advantage of this technique is that it can record the movement of coordinates not only in the x–y direction but also in the z direction.

Measurements were made under loading because cusps deform in response to functional loads. Molar teeth with an MOD and an endodontic access cavity were used because teeth with MOD cavities had

Table 1 The table presents mean cusp movement (the mean of the change between the initial and final width between the reference points marked at the cusp ridges) for each group and mean, standard deviation (SD) value of load at fracture (N)

	Group 1	Group 2	Group 3	Group 4
Change at inter-cuspal width (μm) (P = 0.003)	17.6a	6.7b	6.6b	0.85b
Mean fracture strength values (Mean N ± SD) (P = 0.22)	1798.82 ± 180.87a	1827.95 ± 664.19a	1853.80 ± 297.84a	1524.36 ± 326.73a

Same letters in the same line indicate the statistically similar groups (P > 0.05).

Table 2 Results of modes of failure and distribution of the samples according to the fracture patterns (%)

%	Type 1 Restorable	Type 2 Restorable	Type 3 Non-restorable	Type 4 Non-restorable
Group 1 Control	10	–	70	20
Group 2	–	80		20
Group 3	70	30		–
Group 4	10	80		10

extensive cusp deflection under loading (Reeh *et al.* 1989b). Teeth are continually subjected to stresses during function in oral conditions. Progressive cuspal displacement and delayed recovery with prolonged or cyclical occlusal loading have been reported (Jantarat *et al.* 2001). In this study, although the teeth were subjected to continuous loading, the effects of cyclical loading were disregarded as were other factors such as thermocycling, pH cycling and ageing of materials (Amaral *et al.* 2007). Clearly, this was one of the limitations of this laboratory study.

The first hypothesis of the study that fibre reinforcement during the restoration of teeth with MOD cavities and endodontic access cavities with composite would have no effect on cusp movement is rejected. The composite resin-restored group had significantly greater cusp movement when compared to the other groups. An increased C-factor, which led to increased shrinkage stress at the bonded surfaces, resulted in greater cusp deflection (Lee *et al.* 2007), and reduced volumetric polymerization shrinkage resulted in a reduction in the associated cuspal strain in premolars with MOD cavities (Fleming *et al.* 2005). According to the 'elastic cavity wall concept', the shrinkage stresses generated by a subsequent layer of higher modulus resin-based composites can be absorbed by an elastic intermediary layer (Unterbrink & Liebenberg 1999). Cuspal deflection in a class II cavity (Alomari *et al.* 2001) and in molars with MOD cavities (Cara *et al.* 2007) reduced with the usage of a flowable intermediary resin. Polyethylene fibre possesses a dense concentration of fixed nodal intersections that assist in maintaining the integrity of the fabric. This enables the stresses in the bulk of the material to be transferred more effectively because of the well-defined load paths from one area to another (Belli & Eskitascioglu 2008). Although the effects of flowable resin were not evaluated separately in this study, an elastic layer was created with flowable resin and polyethylene fibre in group 2. The results indicated that this technique caused less cusp movement than group 1. The elastic layer created by polyethylene fibre and flowable resin and its modifying effect on the interfacial stresses (Eskitascioglu *et al.* 2002, Belli & Eskitascioglu 2008) might have contributed to decreasing the cusp movement that occurred because of shrinkage stresses.

The fracture tests using fibre-reinforced composite restoration techniques indicated that use of fibres under (technique 2) or over (technique 3) composite resin significantly increased the fracture strength (Belli *et al.* 2005a,b, 2006a,b). In contrast to these previous studies, root canal preparation, irrigation and canal filling procedures were not included in this study, and the technique used to prepare MOD cavities was also different. The influence of root canal instrumentation and canal filling either led to reductions in the resistance to fracture (Trope & Ray 1992) or had little effect on tooth biomechanics (Reeh *et al.* 1989b). The action of irrigants and medicaments (Grigoratos *et al.* 2001), the effect of moisture reduction (Lewinstein & Grajower 1981) and the loss of structural integrity because of access cavity preparation (Hurmuzlu *et al.* 2003) can combine to influence the mechanical properties of root-filled teeth. Furthermore, when extracted human teeth are used, the potential for large variations in strength exists. In this study, no significant differences were found amongst the groups, possibly because of the reasons listed earlier ($P > 0.05$). Thus, the second hypothesis of the study, that fibre reinforcement during the composite restoration of MOD cavities with endodontic access, has no effect on fracture strength must be accepted.

When the fracture modes of the tested samples were evaluated, 80–100% restorable fracture patterns were observed in the fibre-reinforced composite resin groups (Table 2; Fig. 3); these results differ from those of the first group (10% restorable; Fig. 4). This result confirms the concept that polyethylene fibre has a modifying effect on interfacial stresses (Meiers *et al.* 2003), and the use of polyethylene fibre-reinforced composite restoration can save the remaining tooth structure under loading (Eskitascioglu *et al.* 2002, Belli & Eskitascioglu 2008). On the other hand, no correlation was found between the change in intercuspal width with loading and fracture strength. The properties of fibre-reinforced composites are related to the fibre direction (Tezvergil *et al.* 2006). Previously, the fibre orientation was shown to have a pronounced effect on the mechanical properties of fibre-reinforced composite (Dyer *et al.* 2004) and on linear shrinkage strain (Tezvergil *et al.* 2006). Minor shrinkage observed in both directions with bidirectional fibre-reinforced composite resin was explained by the constraints applied by the fibres in both directions. The polyethylene fibre material used in this study has a three-dimensional structure owing to either a leno wave or triaxial architectural design and is composed of a great number of interactions. Taking the structure of the fibre material used into account, it can be hypothesized that the directions of the stresses can be changed because of the properties of the fibre material and its great number of interactions.

Hydration of teeth may potentially influence the amount of cusp movement. Suliman *et al.* (1994) reported that hydrated teeth had less cuspal deflection than dry teeth. Causton *et al.* (1985) found no difference in cuspal deflection when the teeth were stored wet or dry over a 1-week period. According to Jameson *et al.* (1994), adequate provision must be made to maintain tooth hydration throughout any experimental procedure. Dehydration of human dentine resulted in decreased strain at fracture and was reflected as brittle behaviour (Jameson *et al.* 1993). The distinct roles of free water in the dentinal tubules and hydrostatic pressure on the stress–strain distribution within the bulk dentine was reported by Kishen & Vedantam (2007). Because removing the tightly bound water from dentine required heating to more than 600○C (Van der Graaf & ten Bosch 1990) for a considerable period of time, the water lost by this approach was thought to be mostly free water present in the dentine (Kishen & Vedantam 2007). The dentine lost only 5% of water after 72 h of dehydration, and this water constituted only 30% of the total water in the dentine (Kishen & Vedantam 2007). In this study, the teeth were stored in sterile water at room temperature until use and were kept moist throughout the experiment at room temperature (23 ± 1 °C), except when aspects of the experimental procedure required isolation from moisture. Based on the findings mentioned earlier, the effect of hydration or dehydration of the teeth was eliminated in this study by keeping the samples in 100% wet conditions during the experiment.

Conclusions

Regardless of the effect of the restoration technique, fibre reinforcement of composite restorations decreased cusp movement in molar teeth with MOD cavities and endodontic access; however, fibre reinforcement did not affect fracture strength. Thus, polyethylene fibre-reinforced restorations reduce cusp movement under loading but did not have a positive effect on fracture strength.

Acknowledgements

This study was performed in Research Center of Dental Faculty of Selçuk University and supported in part by Scientific Research Projects Coordination Center of Selçuk University (BAP). The materials are generously supplied by the companies. The authors thank Dr Oguz Eraslan from Department of Prosthodontics and Dr Alparslan Gökalp from Department of Pedodontics, Selcuk University, Faculty of Dentistry for their contribution to the schematic drawings.

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