Eur. J. Prosthodont. Rest. Dent., Vol.19, No. 1, pp 25-31
Printed in Great Britain

doi:10.1922/EJPRD_944Geerts07

Fracture Resistance of Endodontically Treated Premolars with Fibre-Reinforced Composite Restorations

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Abstract - *This study investigated the fracture resistance and failure mode of endodontically treated premolars restored with a glass fibre-reinforced composite resin. Endodontically treated maxillary premolars were divided in 4 groups: group O: occlusal access opening restored with direct composite; group O+: as group O but with fibre reinforcement; group MOD: occlusal access opening and mesio-distal (MOD) cavity restored with direct composite; group MOD+: as group MOD but with additional fibre reinforcement. Pairwise comparisons of the fracture force among all groups was performed (95% confidence level). Fractures were classified in 4 groups depending on the type of fracture. Group O was the strongest (452.7N) and group MOD the weakest (292.4N). Fracture resistance was significantly different among all groups, except between groups O+ and MOD+. The majority of the unreinforced teeth displayed unfavourable fractures, while the reinforced teeth displayed more favourable fractures. The incorporation of glass fibre weakened endodontically treated but otherwise intact premolars; premolars with MOD restorations were stronger if reinforced with fibres. Fibre reinforcement led to more favourable fractures.*

KEY WORDS: Composite restoration; glass fibre; fracture resistance

INTRODUCTION

Endodontically treated teeth are considered to be structurally weakened as a result of coronal destruction from dental caries, trauma, previous restorations and endodontic procedures[1,2]. According to Reeh *et al*. (1989) endodontic procedures reduced cuspal stiffness of premolars by 5%, but a mesio-occluso-distal (MOD) cavity preparation reduced it by 63%[3]. Sengun *et al*. (2008) confirmed that the presence of an MOD cavity preparation significantly reduced the fracture resistance of extracted root canal treated (RCT) mandibular premolars[4]. Soares *et al*. (2008) found that RCT maxillary premolars with MOD cavity preparations for indirect restorations had significantly lower fracture resistance than those with MOD cavity preparations for direct restorations[2]. This difference was attributed to the more conservative nature of direct restorative preparation designs. Nagasiri & Chitmongkolsuk (2005) reported that remaining coronal tooth structure and types of restorative material have a significant association with tooth survival and that RCT molars with maximum tooth structure remaining can be restored with direct restorations, with an estimated survival probability of 0.96, 0.88 and 0.36 for 1-, 2- and 3-year periods respectively[5].

Many different techniques and materials have been researched in the quest to find the ideal restoration for the RCT tooth. The complete cast coverage has been considered the gold standard[6]. In the search for less invasive, faster and cheaper solutions, different techniques and materials have been tried with mixed results[7-12]. Yamada *et al*. (2004) found that fracture resistance was higher for RCT maxillary premolars restored using a cast-metal onlay cemented with adhesive cement, than for those restored using direct and indirect inlay and onlay adhesive resin composite restorations[13]. Several publications report that premolars with MOD cavities gained strength from adhesive restorations[2,4,14-16].

Recent developments in fibre-reinforced composite technology have created new opportunities for providing minimally invasive, aesthetic, metal-free and adhesive direct restorations. *In vitro* testing proved the reinforcement potential of glass fibres used in composite resins[17]. Belli *et al*. (2005) found that the use of polyethylene ribbon fibre in a bucco-lingual direction under composite restorations in RCT mandibular molars with MOD preparations significantly increased fracture strength compared with composite restorations without fibre reinforcement[18]. In a later study, they found that the application of a fibre over an adhesive restoration increased fracture resistance more than when the fibre was placed against the floor of the cavity[19].

Besides the strength of a restored tooth, the failure mode in the event of fracture is also important. More favourable fractures are reported for premolars restored with fibre-reinforced composite restorations (FRC), than for restorations without fibres[4,20].

The aims of this study were to assess the *in vitro* fracture resistance and to analyze the fracture mode of root canal treated premolars restored with direct composite restorations with and without glass fibre reinforcement. The null-hypotheses were: 1) there is no difference in fracture

* BChD, PDD, MChD
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‡ BDS

resistance between RCT premolars restored with direct composite restorations with and without glass fibre reinforcement, and 2) there is no difference in fracture mode between RCT restored with direct composite restorations with and without glass fibre reinforcement.

MATERIALS AND METHODS

The research proposal was reviewed and approved by the research and ethics committee of the Faculty of Dentistry of the University of the Western Cape. Fifty seven intact extracted permanent maxillary premolar teeth were collected. They were examined using a light microscope (Nikon SMZ-1) under 10x magnification to ensure that they were free of caries, fracture lines, cervical abrasion and injury from extraction forceps. The teeth were stored in saline. Endodontic access cavities were prepared using a water-cooled diamond bur (Endo Access Bur FG 2). The dimension of the access opening was dictated by the dimension of the bur (1.37 mm diameter round tip, tapering to a diameter of 1.83 mm at a distance of 10.4 mm away from the tip) and by the size of the pulp chamber. The occlusal anatomy and the external root surface guided the position and direction of the access opening. Root canal openings were located with a probe (Micro-Opener) and cavity walls were carefully finished ensuring that no sections of the pulpal roof remained. The access openings were performed by one operator and checked by a second operator for the absence of damage to the cavity walls and pulp chamber floor. Damaged teeth were to be discarded and replaced. Root canals were prepared to a size 30 0.6 tapered nickel titanium file (ProFile) and filled with gutta percha (DiaDent) together with an epoxy endodontic cement (Topseal) using cold lateral condensation. The floor of the access cavity was sealed with a thin layer of glass ionomer material (Vitremer).

The cementoenamel junction (CEJ) of each tooth was established using a light microscope (Nikon SMZ-1) under 10x magnification, and marked using a fine waterproof marker. A second line 2 mm coronal to the CEJ was made and indicated the intended floor of the MOD cavity. A third mark 1 mm apical to the CEJ was made indicating the level for embedding in acrylic resin.

The prepared teeth were randomly divided into 4 groups.

The teeth in group O (control) had their access opening incrementally restored using composite restorative material (Filtek Z250). The teeth in group MOD (control) received a MOD cavity with a bucco-palatal width of 2 mm and the cavity floor 2 mm above the CEJ using a straight diamond bur (Horico 157 016). This bur has a flat tip with slightly rounded edges resulting in a flat cavity floor with rounded internal line angles. The width of the cavity and the distance away from the CEJ junction were checked using digital callipers (Shengya Machine & Tools Co), with 0.01 mm accuracy, using a light microscope (Nikon SMZ-1) under 10x magnification. The occlusal central fissure and the occluso-cervical axis of the crown guided the position and the direction of the cavity. The MOD cavity was restored using the same composite restorative material as for group O.

The teeth in group O+ were restored in the same way as the teeth in group O. After the restoration, a buccopalatal occlusal groove was prepared, 2 mm wide and 2 mm deep, with a step extending 1 mm apically onto the buccal and palatal surface, as described by Belli *et al*. (2006). The floor of the step, buccopalatally, was approximately 1.5 mm wide. The buccopalatal width of the tooth measured at the level of the floor of the groove determined the length of the glass fibre. The glass fibres selected for this study, were ready-made round bundles of individual fibres encased in a bisGMA and PMMA matrix, with a unique and patented 'interpenetrating polymer network' feature. The fibre bundles are supplied in lengths of 50 mm and a cross-section of 1.00 mm. Before polymerization, the bundle can be bent, moulded and cut into the required shape and length.

A bundle of glass fibres (C&B fibre) was removed from its silicone wrapping as supplied by the manufacturer, cut to length with fingernail clippers and mounted in a flowable composite restorative material (Filtek Supreme XT) that was placed against the floor of the buccopalatal groove. The ends of the glass fibre bundle were tucked into the buccal and palatal steps of the groove. A clear silicone key was used to stabilize the fibre bundle in position during light polymerization. The tip of the polymerization unit (Optilux 400) was held within 1 mm of the surface of the restoration.

For the teeth of group MOD+ the same MOD cavity was prepared and restored as for the teeth in group MOD. Afterwards, the MOD+ teeth received a fibre reinforcement using the same technique as for group O+. (Figures 1 and 2)

All materials were handled in accordance with the manufacturers' instructions. The preparations were performed by one operator and explored for the correct dimensions by a second operator. If the preparations did not conform to the specified dimensions, the preparation was corrected if possible, otherwise the tooth was to be removed from the experiment and replaced by another tooth.

The specimens were subjected to thermocycling at 630 cycles between 5 and 55 C° with a dwell time of 30 seconds.

In order to simulate a periodontal ligament all the roots were dipped in wax (Metrodent no 4) molten in a thermostatic bath (Talleres Mestraitua) at 75°C, up to 1 mm from the most apical part of the CEJ. The teeth were embedded in auto-polymerizing acrylic resin (Wright Cottrell) using plastic piping (DPI Plasticd) with a 20 mm diameter and 20 mm height, up to the highest level of the wax. After polymerization of the resin, a silicon key was made using polyvinyl siloxane putty impression material (Lab-Putty) covering the tooth and the upper periphery of the plastic pipe. The tooth together with the silicon key was separated from the resin. The wax was removed from the root surface and resin mould by rinsing with hot water. A relief hole connecting the apical part of the simulated tooth socket and the base of the resin mould was created using a small round bur. Silicon impression material (President regular body) was injected into the resin mould, uniformly coating the tooth socket with a thin layer of impression material. The tooth was re-inserted in its original position using the silicon key before the impression material had set. The bucco-palatal and mesio-distal crown widths of each tooth were measured 3 times at the point of greatest curvature using digital calipers (Shengya Machine & Tools Co) up to 0.01 mm accuracy. The mean of these readings was accepted as the definitive measurement.

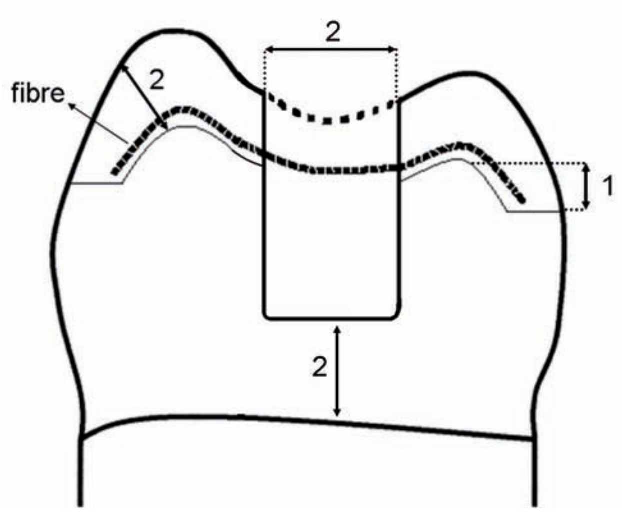

Figure 1. *Graphic illustration of the bucco-palatal cross section showing the outlines and dimensions in mm of the MOD cavity and position of the fibre in the bucco-palatal groove, based on a technique described by Belli et al. (2006).*

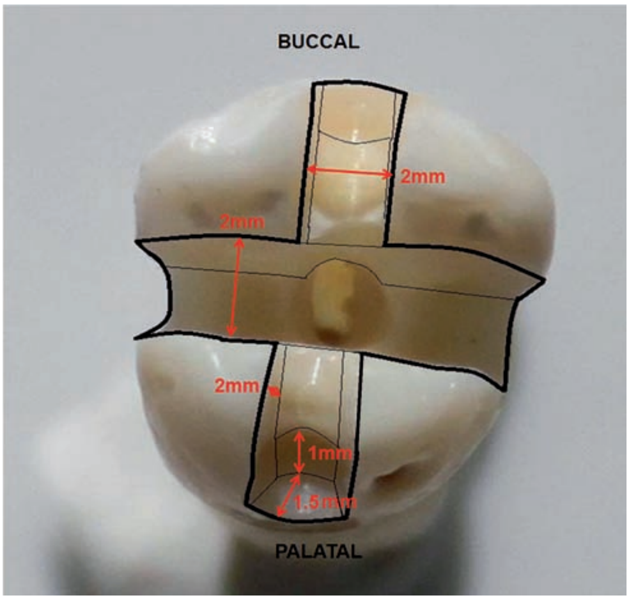

Figure 2. *Photographic image of the occlusal view with the outlines and dimensions of the MOD cavity and bucco-palatal groove for the fibre, based on a technique described by Belli et al. (2006).*

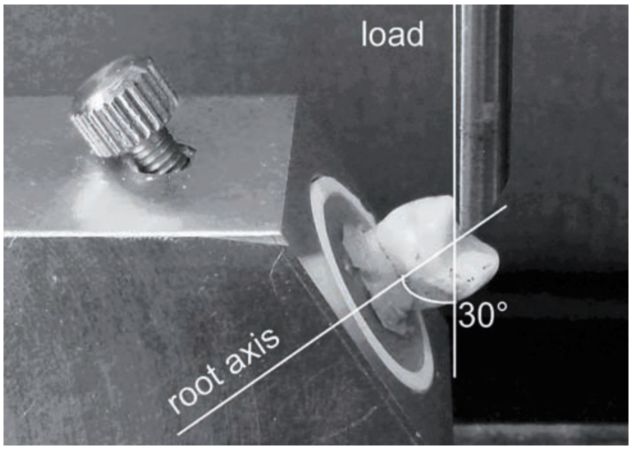

Figure 3. *Position of the specimen in the test rig.*

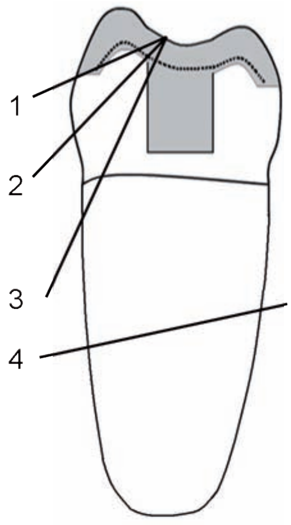

Figure 4. *Schematic representation of the 4 fracture types. 1= type 1 fracture (#), 2 = type 2#, 3 = type 3# and 4 = type 4#.*

Specimens were stored in saline for a minimum of 24hrs at 37ºC before testing. The specimens were placed in a universal testing machine (Zwick) using a custom made base so that the long axis of the roots was at a 30 degree angle to the direction of the load. The load was applied using a crosshead speed of 1mm/min and 0.5kg load cell by means of a bevelled rod with a round tip placed over the central fissure of the occlusal surface in the direction of the buccal cusp. (Figure 3) Halfway its length, the circular rod was bevelled to produce a semicircular rod with a flat surface on the one side. This flat surface was placed close to the lingual cusp of the tooth allowing the round tip to be positioned over the central fossa. The maximum force before fracture was recorded.

After testing, the fractured specimens were perfused with methylene blue (Novalek) to highlight the fracture lines. The fractures were classified as follows: type 1: fracture within the coronal third, type 2: fracture above the CEJ, type 3: oblique fracture extending to the root, type 4: complete root fracture. (Figure 4) The failure mode was evaluated by 2 observers both visually and by means of a light microscope (Nikon SMZ-1) using 10x magnification. Disagreements were resolved by discussion.

To determine the influence of tooth dimension on the fracture strength, least squares regression analysis was performed for the 4 groups. To determine differences among groups, pairwise comparison of the values adapted by means of the linear equations derived from the least

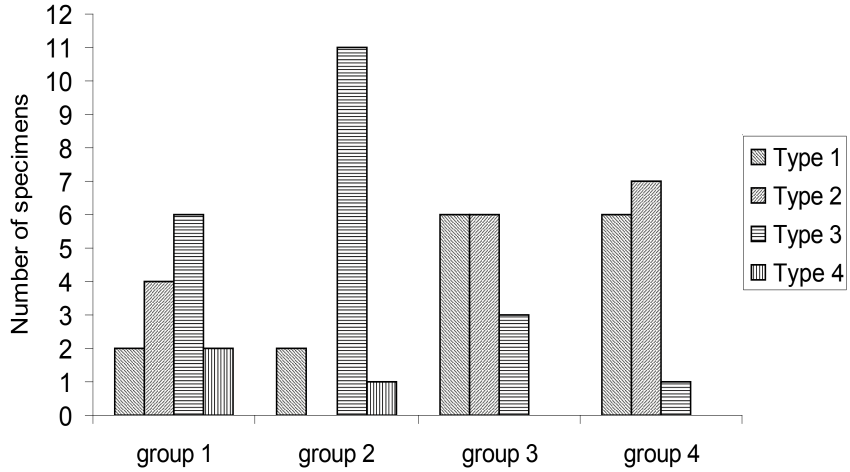

Figure 5. *Bar chart representing the numbers within each fracture type group.*

squares regression analysis was performed using the Wilcoxon signed rank sum test, with a 95% confidence level.

Frequencies of 'restorable', 'dangerous' and 'catastrophic' failures among groups were compared. Type 1 and 2 fractures were considered 'restorable'; type 3 fractures present a clinically more challenging situation to restore and were categorized as 'dangerous'; type 4 fractures often imply loss of the tooth and were categorized as 'catastrophic'.

RESULTS

None of the teeth were removed and replaced due to damage during preparation procedures and all 57 teeth were included in the study.

The averages of the maximum load before fracture (F_{max} in Newton) for the 4 groups are shown in table 1. The average estimated area in table 1 refers to the product of the mesio-distal and bucco-lingual dimensions of the teeth. Least squares regression analysis showed a positive correlation between tooth dimension and fracture values for groups O, MOD and MOD+, but not for group O+. Table 2 shows the results of the simple linear regression for the 4 groups. The R^2 values were all higher than 0.211, except for group O+ ($R^2 = 0.050$), indicating a poor prediction of tooth dimension and fracture value. Four values were identified that caused the abnormal bivariate distribution and these were removed from the data set. Non-parametric analysis of variance of the reduced data set for group O+ showed a positive correlation between tooth size and fracture value ($R^2 = 0.0427$), fitting in with reasonable expectations.

Pairwise comparison of the predicted averages between the 2 control groups, O and MOD, showed a significant difference in fracture values (P = 0.001). There were also significant differences between groups O and O+ (P = 0.001), and between groups MOD and MOD+ (P = 0.0015). There was no difference between groups O+ and MOD+ (P = 0.1549).

All specimens were examined for fracture type. Figure 5 shows a bar graph with the number of each fracture type within each group. Table 3 groups the type of fracture according to the presence or absence of fibre-reinforcement. This table also demonstrates that 25 of the 33 more favourable fractures were from teeth with FRC restorations. Twenty of the 24 more unfavourable fractures were from teeth restored without fibre-reinforcement. There were no complete root fractures in the groups with FRC restorations.

DISCUSSION

Both null-hypotheses were rejected, except for the difference in fracture resistance between groups O+ and MOD+.

Least squares regression analysis showed a positive correlation between tooth dimension and fracture values for groups O, MOD and MOD+. It was indeed to be expected that a larger tooth fractures at a higher load. However, the negative correlation for group O+ was unexpected. Four observations in the O+ group were unusually high and these outliers were excluded from the analysis, because the nature of the covariant causing these 4 unusually high observations is unknown and this phenomenon was not observed in the other groups. This resulted in a lower F_{max} for the O+ group with the reduced data set and a bigger difference between groups O and O+, although the overall results in terms of the pairwise comparisons remained similar.

A significant difference in strength between the 2 control groups, O and MOD, demonstrated the weakening effect of an MOD cavity on the fracture resistance of a maxillary premolar. This phenomenon has been illustrated in previous studies[2-4].

The incorporation of a fibre in a buccopalatal groove for a RCT but otherwise intact maxillary premolar weakened the tooth. This may be attributed to the additional removal of tooth structure necessary to incorporate the fibre.

The results of this study are not in agreement with the results obtained by Sengun *et al.* (2008) [4]. Using a similar technique as in this study, they did not find a difference in fracture resistance in premolars restored with composites with and without fibres. However, Sengun and co-workers used polyethylene fibres. In that same study, most of the failures for the fibre-reinforced group were enamel level fractures, while fractures of the non-reinforced group were

Table 1. *Average values for maximum load before failure (F_{max}) and range in Newton (N) for the 4 groups (full and reduced data sets). The shaded pair of groups does not differ significantly.*

Group	*n*	*Average estimated area (mm²)*	*Average F_{max} (N)*	*Range*
O	14	63.65	452.7	317.7-548.9
O+	15	63.60	354.6	227.5-527.8
O+ (reduced data set)	11	64.70	307.6	227.5-379.2
MOD	14	69.90	292.4	221.3-450.4
MOD+	14	69.35	325.7	207.1-506.1

Table 2. *Simple linear regression analysis of the full data set. The shaded cells highlight the negative slope and low R^2 value for group O+.*

	O n=14			*O+ n=15*	
Slope	*Intercept*	*R^2*	*Slope*	*Intercept*	*R^2*
4.553	162.9	0.211	-4.087	614.6	0.050
	MOD n=14			*MOD+ n=14*	
Slope	*Intercept*	*R^2*	*Slope*	*Intercept*	*R^2*
5.713	-107.0	0.315	5.281	-40.6	0.294

Table 3. *Fracture types according to groups. #1 = type 1 fracture. #2 = type 2 fracture. (#1 and #2 are considered 'restorable fractures' because they are above the CEJ).*

Group	*Fibre*	*#1 restorable*	*#2 restorable*	*#3 dangerous*	*#4 catastrophic*	*n*
O (control)	no	2	4	6	2	14
MOD (control)	no	2	0	11	1	14
O+	yes	6	6	3	0	15
MOD+	yes	6	7	1	0	14
n		16	17	21	3	57

#3 = type 3 fracture, 'dangerous fracture'(more challenging to restore because it is below the CEJ).
#4 = type 4, 'catastrophic fracture' (root fracture).

lower level fractures (dentine, CEJ and root fractures). The same results were found in this study. Table 2 clearly demonstrates the cluster of unfavourable fracture types (shaded area) belonging to the non-reinforced groups (O and MOD) and the cluster of favourable fracture types (shaded area) belonging to the reinforced groups (O+ and MOD+). The fibre-reinforcement provided for partial coverage of the cusps that was lacking in the non-reinforced group. The more favourable fracture patterns for this group may be partially attributed to this feature.

The results of this study confirm the findings by Belli *et al.* (2005).[18] They found that polyethylene ribbon fibre increased fracture strength of RCT mandibular molars with MOD cavities. If the fibre was placed *over* the MOD composite restoration the reinforcement effect was significantly higher than when it was placed at the base of the restoration[19]. Therefore, the technique of placing the fibre over the restoration was used in the present study.

Thermocycling was performed to simulate moisture and temperature changes in the mouth. A periodontal ligament was simulated. Soares *et al.* (2005) reported that the simulation of a periodontal ligament modified the fracture mode, with a greater prevalence of fractures at the root portion[21].

It is important to note that the application of a continuous compressive force, as done in this study, does not represent the intraoral environment. *In vitro* cyclic loading simulates *in vivo* forces of mastication and could influence the results. This should be considered a study limitation.

There were 6 premolars showing bifurcation in the apical 1/3 of the root, 2 each in the O and MOD group, and 1 each in the O+ and MOD+ groups. Of a total of 3 root fractures, 1 belonged to a premolar with a double root. The other 2 root fractures belonged to single rooted premolars. These numbers are too small to make a correlation between root configuration and fracture mode. This aspect could be investigated further.

Endodontically treated maxillary premolars were selected for this study, because they appear to be especially susceptible to fracture. Hansen *et al.* calculated the expected cumulative survival rate of 1639 endodontically treated posterior teeth retrospectively[22]. The lowest survival rate was found for the upper premolars with an MOD cavity (restored with amalgam): 28% of these teeth fractured within 3 years after endodontic therapy, 57% were lost after 10 years, and 73% after 20 years.

The width and the depth for the MOD cavities were standardized. To reduce the influence of tooth size on fracture values, the force values of the groups were adapted by means of linear equations before the pairwise comparisons were done. Table I refers to the average 'estimated' area in mm^2, being the product of the mesio-distal and buccolingual dimensions at the point of greatest curvature of the tooth. However, a cross section of a tooth is not a perfect rectangle and therefore the surface area should be regarded as an estimate. This is a study limitation.

Development of new materials and techniques requires continuous *in vitro* and *in vivo* studies. Adhesive glass fibre reinforced composite resin restorations are among these new developments. In recent years, several *in vitro* studies have shown the reinforcement effect of fibres in composite restorations. Controlled prospective clinical trials would provide the most reliable data on the prognosis of teeth restored with the technique presented here. But these studies are ethically prohibitive. Well executed retrospective clinical studies involving patients who received this treatment option because of financial, time or age constraints, can serve as an alternative to fully evaluate the efficacy of this treatment modality.

CONCLUSION

Within the limitations of this *in vitro* study it may be concluded that:

1. The presence of a restored MOD cavity decreased the fracture resistance of endodontically restored maxillary premolars.
2. Endodontically treated premolars with MOD restored cavities, were strengthened by the use of fibre, but remained significantly weaker than premolars with endodontic access openings only.
3. The cutting of a buccopalatal groove and the incorporation of glass fibres within this groove weakened endodontically treated but otherwise intact premolars.
4. The inclusion of glass fibre in the restoration of endodontically treated maxillary premolars led to a more favourable breaking pattern in the event of tooth fracture.

ACKNOWLEDGEMENTS

University of the Western Cape for financial support and StickTeck for donating the fibres.

MANUFACTURERS' DETAILS

- Nikon SMZ-1, Tokyo, Japan
- Endo Access Bur FG 2, Maillefer, Ballaigues, Switzerland
- Micro-Opener, Maillefer, Ballaigues, Switzerland
- ProFile, Maillefer, Ballaigues, Switzerland
- DiaDent, Cheongiu-si, Choongchong, Buk-do, Korea
- Topseal, Maillefer, Ballaigues, Switzerland
- Vitremer, 3M ESPE Dental Products, St. Paul, MN, USA)
- Filtek Z250, 3M ESPE Dental Products, St. Paul, MN, USA
- Horico 157 016, Berlin, Germany
- Shengya Machine & Tools Co, Qingdao, China
- C&B fibre, Stick Tech Ltd. Turku, Finland
- Filtek Supreme XT, 3M ESPE Dental Products, St. Paul, MN, USA
- Optilux 400, Demetron Research Corporation, CT, USA
- Metrodent no 4, Metrodent Ltd, Huddersfield, England
- Talleres Mestraitua, Sondika-Bilbao, Spain
- DPI Plasticd, Cape Town, South Africa
- Lab-Putty, Coltène/Whaledent, Altstätten, Switzerland
- President regular body, Coltène/Whaledent, Altstätten, Switzerland
- Zwick, Ulm, Germany
- Novalek, Hayward, CA, USA

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