Fracture resistance of endodontically treated maxillary premolars restored by silorane-based composite with or without fiber or nano-ionomer

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PURPOSE. This *in vitro* study investigated the fracture resistance of endodontically treated premolars restored using silorane- or methacrylate-based composite along with or without fiber or nano-ionomer base. **MATERIALS AND METHODS.** Ninety-six intact maxillary premolars were randomly divided into eight groups (n = 12). G1 (negative control) was the intact teeth. In Groups 2-8, root canal treatment with mesio-occlusodistal preparation was performed. G2 (positive control) was kept unrestored. The other groups were restored using composite resin as follows: G3, methacrylate-based composite (Z250); G4, methacrylate composite (Z250) with polyethylene fiber; G5 and G6, silorane–based composite (Filtek P90) without and with the fiber, respectively; G7 and G8, methacrylate- and silorane-based composite with nano-ionomer base, respectively. After aging period and thermocycling for 1000 cycles, fracture strength was tested and fracture patterns were inspected. The results were analyzed using ANOVA and Tukey HSD tests (α=0.05). **RESULTS.** Mean fracture resistance for the eight groups (in Newton) were G1: 1200 ± 169[a], G2: 360 ± 93[b], G3: 632 ± 196[c], G4: 692 ± 195[c], G5: 917 ± 159[d], G6: 1013 ± 125[ad], G7: 959 ± 148[d], G8: 947 ± 105[d] (different superscript letters revealed significant difference among groups). Most of the fractures in all the groups were restorable, except Group 3. **CONCLUSION**. Silorane-based composite revealed significantly higher strength of the restored premolars compared to that of methacrylate one. Fiber insertion demonstrated no additional effect on the strength of both composite restorations; however, it increased the prevalence of restorable fracture of methacrylate-based composite restored teeth. Using nano-ionomer base under methacrylate-based composite had a positive effect on fracture resistance and pattern. Only fiber-reinforced silorane composite restoration resulted in a strength similar to that of the intact teeth. ***[J Adv Prosthodont 2014;6:200-6]***

KEY WORDS: Endodontically treated premolar; Intracoronal direct restoration; Silorane-based composite; Polyethylene fiber; Nano-ionomer; Fracture resistance

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Received November 22, 2013 / Last Revision March 11, 2014 / Accepted March 17, 2014

This study was supported by a grant (Grant# 92-6725) of the Vice-chancellery of Shiraz university of Medical Sciences.

INTRODUCTION

The choice of an optimal restoration for endodontically treated (ET) teeth that guarantee the success of endodontic treatment remains controversial. In addition to providing function, esthetic and marginal sealing, the restoration should protect the remaining tooth structure.[1,2]

The loss of marginal ridges, the removal of pulp chamber roof along with inner dentin (axial walls) and the resultant cuspal deflection,[1,3-6] along with the loss of the protective feedback mechanism in the non-vital teeth contribute to the high fracture susceptibility of the teeth.[7] In particular, a high incidence of fracture in ET maxillary premolars

pISSN 2005-7806, eISSN 2005-7814

has been reported due to the susceptibility of their anatomic form to separation, unfavorable crown/root proportion and their exposure to both shear and compressive forces.[8,9]

There is no agreement among scholars on definite restorative protocol for ET teeth with variable remaining tooth structure, especially when excessive structure has not been lost. The preservation of sound structure is considered as the primary importance in increasing the longevity of ET teeth.[5,10]

An ongoing trend toward conservative approaches to maintain the structural integrity of the ET teeth has resulted in intracoronal strengthening of such teeth with mesio-occlusodistal (MOD) preparation by different adhesive restorations.[2-5,10-12] This concept can be reinforced following advancements in the new adhesive materials.

On this base, the results of some *in vitro* studies indicated that cusp capping of ET premolars with the adhesive technique was not necessary in terms of cuspal fracture resistance in normal occlusion.[2,12-15] Regarding the post insertion in adhesive restorations, it was assumed that fiber posts with an elastic modulus similar to the dentin can better absorb the forces concentrated along the root, providing a resistance to root structure.[9,16] Nevertheless, they do not reinforce the coronal structure; even additional post-space preparation leads to a weakened tooth structure. And adhesive cemented post creates an additional adhesive interface, contributing to microcrack propagation; as a consequence, fracture strength of the restored teeth is reduced or not altered.[2,12,14,17-20]

Adhesive splinting between the facial and lingual cusps is capable of reducing cuspal flexures, providing internal strengthening.[4,11,12] Although resin composites with low elastic modulus similar to the dentin are preferred for adhesive restoration of ET premolars,[10,21] their major shortcoming, polymerization shrinkage, is still present.[5] In particular, a high polymerization shrinkage stress in deep cavities with a high C-factor following endodontic access preparation might be created.[22] This stress is higher in tooth than within the restoration and adhesive interface in larger restorations.[23]

Fiber reinforced composites were suggested to reduce polymerization shrinkage, increase toughness and impact strength and reinforce resin composite and remaining tooth structure, thereby enhancing fracture resistance of the restored teeth.[24,25] The higher modulus of elasticity and the lower flexural modulus of the polyethylene fiber were proposed to have a modifying effect on interfacial stresses developed along adhesive interface.[26]

The use of low shrinkage silorane-based composite might reduce cuspal deflection.[27] The combination of the fiber and silorane-based composite may be a promising method in terms of fracture resistance.

Recently, reproducing the axial wall using glass ionomer core in composite restoration of MOD ET premolars was found to show the fracture strength approximately similar to that of intact teeth.[28]

A novel highly packed nanofilled resin-modified glass ionomer, nano-ionomer (NI) with a lower polymerization shrinkage and coefficient thermal expansion, higher mechanical properties and better handling properties[29] may be used as a core under composite resin. The combination of NI base with silorane composite has recently been reported to be well performed in deep Class II cavity in terms of marginal sealing.[30]

This study was conducted to compare the effect of using the polyethylene fiber and NI core in methacrylate- or silorane–based composite restorations on fracture resistance of ET maxillary premolars.

MATERIALS AND METHODS

Following the approval of the research protocol by the local ethics committee, 96 sound, noncarious, single-root maxillary premolars extracted for orthodontic treatment were used. The root and crown of the teeth were similar in size and shape and were stored in 0.5% thymol solution at 4ºC. The cleaned teeth were carefully inspected under a stereomicroscope (Carl Ziess, Oberkochen, Germany) at 20× magnification to exclude the teeth with defects, such as fracture lines. The teeth were then randomly divided into eight groups of 12 teeth and each was subjected to the following procedures:

- Group 1: Unaltered intact teeth without any cavity preparation were used as the negative control (G1, NC).
- Groups 2-8: Endodontic access cavities were prepared with a high-speed diamond bur under constant water cooling, and the canals were instrumented with #10 to #40 K-files (Mani Inc., Tochigi, Japan) and distilled water. The canals were dried with absorbent paper points and obturated with laterally condensed gutta-percha cones (Ariadent, Tehran, Iran) and AH26 sealer (DensplyDeTrey, Konstaz, Germany). MOD cavities were prepared down to the canal orifice with the gingival margin placed 1mm apical to the cemento-enamel junction. The buccolingual width of each cavity was one-third of the intercuspal distance at the occlusal isthmus and one-third of the bucco-lingual width of the crown at two boxes with parallel walls, and the cavities extended into the pulp chamber so that axial between the proximal box and the pulp chamber was removed. Measurements were made with a digital caliper (Mitutoyo Digimatic, Mitutoyo, Kawasaki, Japan) with 0.1-mm sensitivity for proper and accurate standardization of cavity dimensions. In Group 2, MOD-prepared only, these teeth were not restored and were used as the positive control (G2, PC).

  In Groups 3-8, the prepared teeth were restored.
- Group 3 (ComZ): All cavity surfaces were etched with 37% phosphoric acid (3M ESPE, St. Paul, MN, USA) for 15 seconds, rinsed for 20 seconds, and gently air-dried, leaving the tooth moist. Two consecutive coats of Adper Single Bond (3M ESPE) were applied and gently dried for 2 to 5 seconds, then light-cured for 10 seconds with a halogen light unit (VIP Junior, Bisco, Schaumburg, IL, USA) at 600 mW/cm^2 light intensity. The cavities

were then restored with a methacrylate- based composite (Z250, 3M ESPE) using an oblique incremental technique. Each layer was placed at 1.5 mm thickness and cured for 40 seconds with the same unit.

- Group 4 (FRCZ): After etching and bonding similar to Group 3, a flowable composite (Filtek Flow, 3M ESPE) coated the cavity surfaces. Before curing, a piece of polyethylene ribbon fiber (3 mm width, 6.5 mm long) (Ribbond Inc., Seattle, WA, USA) was cut and saturated with resin and then embedded inside the flowable composite coated buccal and lingual walls and cavity floor in a buccal to lingual direction (u-shaped) from the occlusal one-third of the buccal wall to the occlusal one-third of the lingual wall. After curing for 20 seconds, the cavities were restored with Z250 composite as performed in Group 3.
- Group 5 (ComS): The self-etching primer of Silorane Adhesive System (3M ESPE, St. Paul, MN, USA) was applied to the cavity for 20 seconds and gently air dried for 10 seconds, and light-cured for 10 seconds. Bond was applied and light-cured for 10 seconds. Silorane-based composite (Filtek P90, 3M ESPE, St. Paul, MN, USA) was applied and cured similar to Z250 in Group 3.
- Group 6 (FRCS): After bonding procedures in the same manner as described in Group 5, the cavity was coated with a layer of the preheated (at 55ºC) silorane composite. Immediately, the prepared fiber similar to Group 4 was embedded inside the preheated silorane composite. Similar to Group 5, the restoration was completed.
- Group 7 (NI/ComZ): Nano ionomer primer (Ketac Nano primer, 3M ESPE) was applied for 15 seconds, air dried, and light-cured for 10 seconds; then two pastes (Ketac N 100) were mixed and placed above the gutta-percha to reproduce the floor and axial wall of the MOD cavity in vital teeth. The cavity was restored with Z250 similar to Group 3.
- Group 8 (NI/ComS): Ketac N100 was applied as described for Group 7 and the restoration was completed with silorane composite similar to Group 5. The eight groups were presented in Fig. 1.

All the preparations and restorations were performed by the same operator. Throughout the experiment, in order to prevent dehydration of the teeth, they were handled in moist gauze and stored in an incubator at 37ºC and 100% humidity.

Each tooth was embedded in a block of self-curing acrylic resin (Acropars, Tehran, Iran) surrounded by polyvinyl siloxane impression material up to 2 mm apical to the cemento-enamel junction (CEJ), with the long axis of the tooth perpendicular to the base of the block.

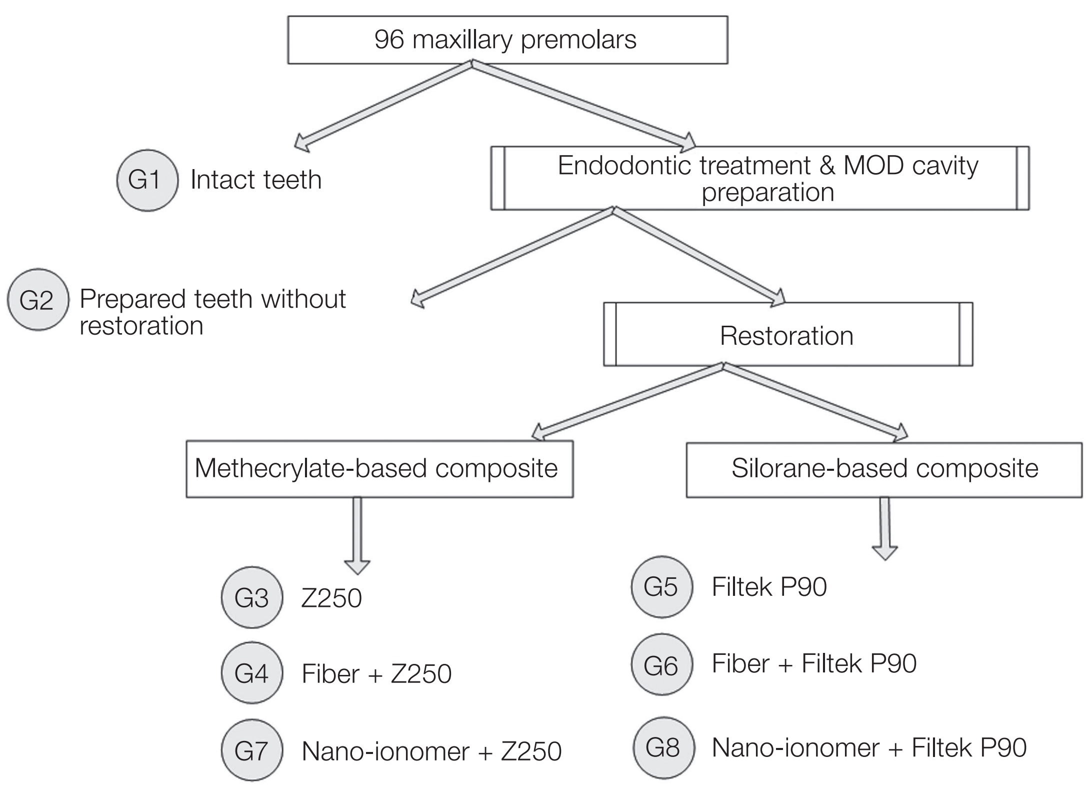

Fig. 1. Descriptive diagram of the eight groups.

Fig. 2. Mode of restorable fracture.

Fig. 3. Mode of unrestorable fracture.

After finishing and polishing the restorations, all specimens were stored in distilled water at 37ºC for six months and thermocycled for 1,000 cycles at 5ºC and 55ºC with a 30-s dwell time according to ISO TR 11454 (1994).

Static fracture resistance testing was performed using a universal testing machine (Zwick-Roell, Zwick, Ulm, Germany). The specimens were subjected to a compressive force at a crosshead speed of 1 mm/min. The force was applied by a 4.8-mm-diameter round the metal bar positioned parallel to the long axes of the teeth, in contact with the occlusal slopes of the buccal and lingual cusps. Peak load to fracture for each tooth was recorded in Newtons (N). Statistical analyses consisted of one-way analysis of variance (ANOVA) followed by the post hoc Tukey HSD test to compare differences between the groups at a significance level of 0.05. All statistical analyses were done in SPSS, version 11.5 (SPSS Inc., Chicago, IL, USA).

The fractured specimens were then evaluated by two independent operators to determine whether the fracture mode was restorable (fractures ending above the CEJ [or less than 1 mm below the CEJ]) or unrestorable (fractures ending more than 1 mm below the CEJ)[31] (Fig. 2 and Fig. 3).

Table 1. Fracture resistance (mean ± SD) in the eight groups

Groups	Mean ± SD (Newtons)
1 (NC, intact teeth)	1200 ± 169[a]
2 (PC, prepared teeth)	360 ± 93[b]
3 (ComZ, Z250 composite)	632 ± 196[c]
4 (FRCZ, fiber + Z250 composite)	692 ± 195[c]
5 (ComS, silorane composite)	917 ± 159[d]
6 (FRCS, fiber + silorane composite)	1013 ± 125[a,d]
7 (NI/ComZ, nano-ionomer + Z250)	959 ± 148[d]
8 (NI/ComS, nano-ionomer + silorane composite)	947 ± 105[d]

Groups with the same letter were not significantly different (P>.05).

RESULTS

Fracture resistance in Newton (mean ± SD) for the eight groups is shown in Table 1. Comparisons with ANOVA revealed significant differences in resistance among the eight groups (P<.001). Group 1 (intact teeth) had the highest resistance (1200 ± 169 N), which was significantly higher than those of all the other groups (P≤.02), except Group 6 (FRCS, 1013 ± 125 N). Group 2 (prepared teeth) had the lowest resistance (360 ± 93 N), which was significantly lower than those of all the other groups (P≤.004).

No significant differences were found between methacrylate Groups (3 and 4), and between silorane Groups (5 and 6), indicating that the fiber had no effect on the resistance. However, Group 5 and 6 showed a significantly higher resistance compared to Group 3 (P≤.002) and 4 (P=.03 and P<.001, respectively).

There was no significant difference among Groups 7 (NI/ComZ), 8 (NI/ComS), 5 and 6 (P>.05). However, these groups revealed a significantly higher resistance compared to Group 3 and 4 (P<.05). The frequencies of restorable and unrestorable fractures are shown in Table 2. Most of the fractures (67-83%) in all the restored groups were restorable, except Group 3. In Group 3, 75% of the observed fractures were unrestorable.

Table 2. Percentage values of restorable and unrestorable fracture in the eight groups

Groups	N	Restorable fracture	Unrestorable fracture
1	12	10 (83.3%)	2 (16.7%)
2	12	5 (41.7%)	7 (58.3%)
3	12	3 (25%)	9 (75%)
4	12	8 (66.7%)	4 (33.3%)
5	12	8 (66.7%)	4 (33.3%)
6	12	9 (75%)	3 (25%)
7	12	9 (75%)	3 (25%)
8	12	10 (83.3%)	2 (16.7%)

DISCUSSION

It is well established that endodontic treatment in MOD prepared maxillary premolars has a remarkable negative effect on the fracture resistance.[3-6,9] This fact was confirmed by the results of the current study. Two resin composites (methacrylate- and silorane–based) used as adhesive restorations were capable of partial re-restoring of the strength of the tooth, which was in accordance with the results of previous studies.[2-4,10-14] The combination of the polyethylene fiber with both composites could not provide a significantly higher fracture resistance.

A number of studies assessed the effect of fiber-reinforced composite on the strength of the posterior teeth and reported different results depending on the type of fiber used, different techniques of fiber insertion and various testing methods.[6,22,26,32-35] The reinforcing effect of polyethylene fiber with two insertion techniques during axial loading of restored mandibular molars was demonstrated by Belli *et al.*[26,34] They applied the fiber under composite restoration [26,34] or after the completion of restoration by the preparation of a buccolingual groove on the occlusal surface.[26] The latter was demonstrated to increase the fracture resistance compared to those of gingival or middle position of glass fiber in MOD cavity of maxillary premolars.[35] However, this technique revealed no significant reinforcing effect on the strength of mandibular premolars.[32] In addition, this technique required an additional cutting of sound cusp structure in a separate step, complicating the restorative procedure. Taha *et al.*[5] believed that when an MOD cavity was restored incrementally, the cuspal deflection was greater after the polymerization of the first two increments compared to that of the last increment. Nevertheless, according to González-López *et al.*,[36] even if polymerization of the last increment was the main cause of cuspal deflection, insertion of the fiber after the completion of restoration over the composite seems to have no effect in this regard. In the current study, the polyethylene fiber was applied under the composite in the bed of uncured flowable composite (or preheated silorane-based composite) to facilitate the fiber adaptation/integration to composite, similar to those of studies by Belli *et al.*;[26,34] however, it had no effect on the fracture strength. This finding was in agreement with the results of previous reports.[22,33]

According to the results of the present study, low shrinkage silorane-based composite compared to methacrylate-based composite with or without fiber showed a better restorative performance in terms of fracture resistance. The fiber-reinforced silorane composite was the only group which revealed an approximately similar strength to that of the intact teeth.

The deep endodontic access preparation in MOD cavity was found to increase cuspal deflection significantly.[5,37] The slow polymerization reaction and lower shrinkage stress of silorane-based composite might be responsible for the decreased cuspal deflection in MOD-prepared vital premolars[27,37,38] and subsequently for the increased strength.

Although in most of the cited studies, thermocycling was not used, according to Hitz *et al.*,[22] degradation of monomer matrix during thermomechanical loading could have influenced the fiber adhesion to the composite. The thermocycling used in this study along with aging period may affect this adhesion and also bonding stability of the adhesive interface at the cervical margin below CEJ. The stable and effective bonding of Silorane Adhesive system associated with silorane composite may contribute to a higher strength attained for this restored group. The important role of the stability of restoration at the cervical dentin margin of the proximal box during thermomechnical cycling was confirmed by a recent study.[20] However, Taha *et al.*[28] reported that fracture load was unaffected by thermal cycling of glass ionomer/composite restored teeth; nevertheless, it should be considered that cervical margin of the MOD cavities was located inside the enamel.

The use of glass ionomer base under methacrylate composite was found to increase fracture resistance similar to that of the intact teeth in an oblique loading.[28] NI used in this study had an intermediary mechanical properties between composite resin and glass ionomer. In the current study, it was postulated that the lower polymerization shrinkage and good bonding of NI to overlying composite[30] might provide a suitable base which acts as a polymerization stress absorber, thereby increasing the strength of methacrylate composite-restored teeth during axial loading. This core might reduce the polymerization stress and the resultant cuspal deflection while curing the first two layers of methacrylate composite. This reduced deflection resulted in increased resistance. However, using NI had no additional effect on fracture resistance of the silorane-based composite restored teeth.

It seems that the type of composite (low shrinkage) and use of NI core base under methacrylate composite have a more positive effect on fracture strength compared to that of fiber insertion. The causative effect of composite resin and adhesive system and lack of such effect for fiber on cuspal deflection strength was confirmed by a recent study.[6] According to Hürmüzlü *et al*.,[11] bonding effectiveness of restorative system was more important than mechanical properties of restorative materials on the strength of ET teeth.

From clinical point of view, in addition to achieving high fracture resistance, the extension of fracture line and re-restorability of the tooth after fracture are critical factors in tooth diagnosis. It was reported that although full cuspal coverage could improve the strength, it increased the risk of nonrestorable fracture.[13,39] Rodrigues *et al*.[6] believed that high resistance along with destruction of the pulp chamber floor was unfavorable. In their study, insertion of glass fiber over the cured adhesive under the composite did not improve the strength or prognosis of the restored molars.

In the current study, the use of the fiber or NI core associated with methacrylate composite and silorane-based composite could induce restorable fracture while methacrylate composite only resulted in unrestorable fracture.

The beneficial effect of fiber on fracture mode was previously reported.[27] However, in a similar application of the fiber conducted by Belli *et al*.,[26,34] fracture mode was not reported. Oskoee *et al*.[35] concluded that the glass fiber insertion was not capable of preventing unrestorable fracture in the ET premolars. The higher percentage of restorable fracture due to the use of a low-shrinkage composite was demonstrated by Scotti *et al*.[15]

As to the fracture strength and prognosis of the restored premolars, conservative direct restoration with silorane composite with or without fiber or NI and NI/methacrylate composite in a normal occlusion might be a more economical and time-saving method before getting involved in a more complex treatment. Moreover, these suggestive techniques have been reported to improve the marginal sealing,[5,30,39] thereby reducing recurrent caries. On the other hand, silorane composite is also less susceptible to adherence to Streptococcus mutans compared to methacrylate composite that might lead to less vulnerability to recurrent caries.[40] Microleakage and recurrent caries can endanger endodontic treatment and structural integrity of the restored teeth.

Although fracture testing using axial compressive loading with more uniform stress distribution is different from dynamic fatigue loading in clinical situation, it remains a common, repeatable and appropriate method to determine clinical conditions under which fractures can occur. This test is an important source of information on the structural integrity of the restored teeth.[2,41,42] Further *in vitro* research with more accurate simulation *in vivo* conditions and long-term clinical studies are required to confirm the obtained findings in the current study.

CONCLUSION

Within the limitations of the present study, the following could be concluded:

1) All restorative treatments significantly increased fracture resistance of maxillary premolars compared to cavity-prepared one.
2) The fiber insertion revealed no additional positive effect on the strength of the restored teeth using methacrylate- and silorane-based composites; however, it increased restorable fracture of methacrylate-based restored teeth.
3) The use of NI core under methacrylate-based composite had a positive effect on fracture resistance and fracture line.
4) Only FRCS restored teeth revealed a similar strength to that of the intact teeth; however, the other restorative materials except for methacrylate-based composite with or without fiber exhibited comparable results to FRCS in terms of resistance.

ACKNOWLEDGEMENTS

The authors thank to Dr M Vossoughi from the Dental Research Development for statistical analysis, and Dr N Shokrpour from center for Development of Clinical Research at Nemazee hospital for editing English.

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