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Original Article

Effect of polyethylene and glass fibers on fracture resistance of large MOD composite restorations

Niloofar Shadman[1], Shadi Jahansepas[1], Arash Tavakoli Rouzbehani[2]

[1]Department of Operative Dentistry, Faculty of Dentistry, Kerman University of Medical Sciences, Kerman, Iran, [2]Dentist, Faculty of Dentistry, Kerman University of Medical Sciences, Kerman, Iran

ABSTRACT

Background: Fracture resistance of maxillary premolars with deep MOD cavities restored using resin composite, fibers (Ribbond and Angelus), and cuspal coverage with composite is of importance.
Materials and Methods: This experimental study divided 55 sound maxillary premolars into five groups. Group 1: intact teeth. MOD cavities with an occlusal depth of 5 mm, an axial depth of 1.5 mm, and a buccolingual width of 3 mm were prepared in the remaining teeth, Group 2: teeth restored with composite by incremental technique (Bisco Aelite Posterior), Group 3: Ribbond fiber, Group 4: Angelus fiber, and Group 5: 2-mm cuspal reduction and coverage with composite. They were subjected to a fracture strength test after 1000 thermocycles and 100,000 chewing cycles. Data were analyzed using analysis of variance, Tukey, and Chi-square tests. A significance level of $P < 0.05$ was considered.
Results: The fracture strength of the control group, cuspal coverage, and Ribbond fiber were significantly higher than the composite group ($P = 0.01$, $P = 0.02$, and $P = 0.001$, respectively). The Angelus fiber also showed marginally higher fracture strength compared to the composite ($P = 0.098$). The Ribbond fiber exhibited a significantly more favorable failure pattern similar to intact teeth. The difference in failure patterns between the cuspal coverage and Ribbond ($P = 0.009$) and between the cuspal coverage and control ($P = 0.034$) was statistically significant.
Conclusion: The use of Ribbond fiber, Angelus fiber, and cuspal coverage significantly increased the fracture strength of composite restorations compared to conventional composite in deep MOD of maxillary premolars. In addition, the Ribbond fiber resulted in a more favorable failure pattern, similar to that of intact teeth.

Key Words: Cuspal coverage, fiberglass, flexural strength, polyethylene, premolars, resin composite

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Address for correspondence:
Dr. Arash Tavakoli Rouzbehani,
Faculty of Dentistry, Kerman University of Medical Sciences, Kerman, Iran.
E-mail: arashtrr@gmail.com

INTRODUCTION

One of the complex challenges in dentistry is the reduced fracture resistance of teeth after MOD cavity preparation and root canal treatment. In posterior teeth that endure higher occlusal forces, weakened tooth structures and decreased fracture resistance are significant concerns. Various factors impact the fracture resistance of teeth, including cavity size, the

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amount of remaining tooth structure, the force applied, and the mechanical properties of the restorative material used.[1]

One of the key factors in dental restorations is the long-term prognosis, which is directly influenced by the dentist's skill, treatment plan, and the type of restorative material used.[2] No restorative material can fully replace the natural tooth structure; however, the correct restorative approach and suitable materials can greatly aid durability. Direct composite restorations are common in dentistry due to their relatively easy application, esthetics, and favorable mechanical properties. These restorations are often single-visit treatments, allow for conservative preparation, can be repaired, and are less costly than indirect restorations.[3] However, a serious drawback of extensive direct composite restorations is polymerization shrinkage, which can induce stress on cusps, cause microleakage, secondary caries, or even tooth fractures and catastrophic failure.[4]

Modern adhesive systems and resin composites, as well as new restorative protocols, have been developed to enhance the performance of direct composite restorations by increasing bond strength, reducing polymerization stress, and emulating the natural tooth's capacity to distribute forces.[5,6] Modern composites, while strong and rigid, often lack sufficient fracture toughness.[7] Extensive MOD cavities, which diminish the remaining tooth structure and weaken the tooth, require reinforcement. Fiber insertion is a suitable method that has recently gained popularity for strengthening restorations. In addition, cuspal coverage is used to enhance performance and increase the strength of teeth.[8] Fiber-reinforced composites offer improved mechanical properties, especially under dynamic loading.[9] These restorations are also valued for their biomimetic properties, as they ideally provide a non-invasive replacement for lost hard tissues by mimicking the characteristics of natural teeth.[10] Fiber networks absorb stress and redirect it, reducing the risk of fracture at the interface between the restoration and adhesive layers. In addition, they reduce composite volume and minimize polymerization shrinkage.[11] Polyethylene and glass fibers are the most commonly available ones.[12,13] *In vitro* studies have demonstrated that polyethylene and glass fibers significantly improve impact strength, modulus of elasticity, flexural strength, and toughness of composites while reducing microleakage[14,15] and often resulting in fracture above the cementoenamel junction (CEJ) and potentially redirecting crack propagation within the composite structure, which prevents catastrophic fractures and leads to restorable situation. Fibers also bond well with the remaining tooth structures.[5]

Multiple studies have verified the positive impact of fibers on enhancing fracture resistance. For example, Albar *et al*. found that polyethylene fibers increased fracture resistance of restorations, with an even greater effect when fibers were placed in both the axial and gingival walls.[16] Agrawal *et al*. investigated fiber placement and orientation in maxillary premolars with large MOD cavities and reported a significant increase in fracture resistance, particularly when fibers were oriented horizontally in the pulpal and gingival floors.[6] Similarly, Escobar *et al*. reviewed fiber-reinforced restorations in Class II cavities and concluded that glass and polyethylene fibers enhanced fracture resistance compared to nonfiber restorations.[17] Özüdoğru and Tosun concluded that although the use of Ribbond results in a more favorable fracture pattern and reduced microleakage but does not increase fracture strength.[18]

Despite these advantages, fiber-reinforced restorations have limitations, particularly regarding their long-term clinical performance and the interfacial area between fibers and the organic matrix. Intraoral hydrolysis and resultant degradation can weaken this interface over time.[19] More research is needed to optimize composite reinforcement methods that reliably increase fracture resistance.

Maxillary premolars are subjected to high shear, tensile forces. These teeth have heterogeneous anatomy and exhibit variability in crown volume and crown-to-root ratio. Following MOD cavity preparation, they are especially susceptible to fracture due to the loss of marginal ridges.[20,21]

The present study aimed to compare the fracture resistance and fracture patterns of maxillary premolars with MOD cavities restored using composite, fiber-reinforced composites (polyethylene and glass), and cuspal coverage with composite. The null hypothesis was that the various techniques employed in this study would have similar effects on fracture resistance and fracture patterns as those of natural teeth.

MATERIALS AND METHODS

This experimental *ex vivo* study was conducted on 55 healthy maxillary premolars extracted for orthodontic reasons. This study was approved by the Research Ethics Committee under the ethical code IR.KMU.REC.1403.223. Teeth without any decay, fractures, or hypoplastic defects were selected and stored in water at room temperature for up to 3 months before testing. The teeth were divided into five groups. Group 1: intact teeth. In the remaining 44 teeth, an MOD cavity was prepared using an 008-diamond fissure bur (Diatez, Iran) and a high-speed handpiece with water–air cooling. The buccolingual width of the cavity at the occlusal surface was set at 3 mm, positioned in the center of the occlusal groove, with a remaining cusp thickness of approximately 2.5 mm and an occlusal depth of 5 mm. Proximal walls were 1 mm above the CEJ, with a gingival floor width of 1.5 mm and slightly divergent occlusal walls. All line angles were rounded, and a new bur was used after every five preparations. The materials used in this study are listed in Table 1.

In Group 2, after cavity preparation, enamel margins were etched with 35% phosphoric acid (Ultradent, USA) for 20 s and rinsed for 15 s. After blot drying, two layers of All-bond Universal (Bisco, Japan) bonding agent were applied following the manufacturer's instructions. Each layer was air-thinned gently and cured with an LED light-curing unit (Woodpecker, China) for 20 s at an intensity of 800 mW/cm².

Table 1: Characteristics of the used materials in the study

Material name	Manufacturer country	Composition
Aelite posterior composite	Bisco,USA	BisGMA, Ethoxylated Bis A Dimethacrylate, Triethylene Glycol Dimethacrylate
Aelite flow composite	Bisco,USA	Ethoxylated Bis A Dimethacrylate, Triethylene Glycol Dimethacrylate, Polybutanediol Dimethacrylate 600
All-Bond Universal adhesive	Bisco,USA	BisGMA, 2-Hydroxyethyl Methacrylate, 10-Methacryloyloxydecyl Dihydrogen Phosphate, Ethyl 4-dimethylaminobenzoate
Ribbond polyethylene fiber	Ribbond,USA	Triaxial braided polyethylene
Angelus fiberglass	Angelus,Brazil	Preimpregnated silanized E-glass fibers with Bis-GMA
margin bond	Colten,Switzerland	Bis-GMA, Bis-EMA, TEGDMA
phosphoric acid gel	Ultradent,USA	35% phosphoric acid

After a minimum of 5 min to allow for "dwelling time," the cavities were incrementally restored with composite (Bisco Aelite Posterior A3, Bisco, Japan) using 1.5-mm wedge-shaped layers. Each layer was cured for 40 s. After completion, the restorations were finished and polished with diamond burs (Diatez, Iran) at low speed with water–air cooling.

In Group 3, the etching and bonding procedures were the same as in Group 2. Afterward, a thin layer of flowable composite (AeliteFlow, Bisco, Japan) was applied as a hydrophobic layer over the adhesive. A piece of polyethylene fiber (Ribbond-Ultra, Ribbond, USA) was then placed buccolingually in the cavity's pulpal floor, after being pre-wetted with Margin Bond (Colten, Switzerland) for 5 min and stored in a dark environment. The fiber was positioned to cover the pulpal floor and extend 1 mm onto the buccal and palatal walls. The fiber length was approximately 4 mm. A second thin layer of flowable composite was applied over the fibers, and all three layers were cured for 40 s. The remaining cavity was restored similarly to Group 2, and then finished and polished.

In Group 4, the etching and bonding steps were identical to Group 2. Like Group 3, a layer of flowable composite was applied as a hydrophobic layer over the adhesive. A piece of glass fiber (Interlig, Angelus, USA) was then placed buccolingually on the pulpal floor, similar to Group 3, and covered with flowable composite. All three layers were cured for 40 s, and the cavity was restored same way as Group 2.

In Group 5, after cavity preparation, each buccal and palatal wall was reduced by 2 mm. Restorations were done in the same way as in Group 2, but the final layer (1 mm) was shaped with a transparent celluloid crown, pre-formed from a healthy premolar, to standardize occlusal anatomy. The restorations were finished and polished, like previous groups.

All specimens were stored in an incubator (Behdad incubator, Iran) at 37°C in a moist environment for 24 h. Subsequently, the teeth were subjected to 1000 thermal cycles (5°C–55°C) with a dwell time of 30 s and a transfer time of 10s. To simulate the periodontal ligament, the roots of the teeth were coated in a thin layer of melted wax up to 2 mm below the CEJ; the teeth were then embedded in self-curing acrylic (Acropars, Iran) up to 2 mm below the CEJ, positioned vertically, with the long axis perpendicular to the horizon. After initial polymerization, the teeth were removed from the acrylic blocks, the wax around the roots was removed, and a light body silicone impression material (Speedex, Colten, Switzerland) was injected into the acrylic cavity before re-embedding the teeth. This created a uniform silicone layer around the roots, simulating the periodontal ligament.

All samples were subjected to a chewing simulator (SD Mechatronic, Germany) for thermomechanical load cycling. This process included 100,000 cycles under a 30 N force at a frequency of 1.7 Hz, with forces applied via a stainless-steel spherical head (4 mm diameter) perpendicular to the occlusal surface.

Following this, samples underwent fracture resistance testing in a testometric machine (Testometric, Rochdale, England) under continuous compressive load at a speed of 0.5 mm/min. The compressive force was applied with a stainless-steel spherical head (4 mm diameter), positioned parallel to the long axis of each tooth and contacting the cusp inclines. Force was applied until fracture occurred, and the maximum force at the fracture point was recorded in Newtons. Fractured specimens were then collected for analysis of fracture patterns.

Fracture types were classified into two categories based on the fracture location: favorable (up to 1 mm below the CEJ) and unfavorable (below 1 mm under the CEJ). Two evaluators conducted the fracture pattern analysis with magnification.

Statistical analysis was performed using SPSS v26 (IBM Corp. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp; 2019). Means, standard deviations, and other descriptive statistics were calculated for fracture resistance values (in Newtons) across different groups. Data distribution was confirmed as normal using the Kolmogorov–Smirnov test. One-way analysis of variance (ANOVA) was used to compare fracture resistance among groups. *Post hoc* pairwise comparisons were made with Tukey's test. Fisher's exact test was used to compare the frequency of favorable and unfavorable fractures across groups, with statistical significance set at $P < 0.05$.

RESULTS

The normal distribution of data was confirmed using the Kolmogorov–Smirnov test. The mean fracture resistance values are presented in Figure 1, with the highest mean fracture resistance observed in the control group (825.82 N) and the lowest in the conventional composite group (495.1 N).

The differences in fracture resistance among the groups were statistically significant, as indicated by the ANOVA test ($P = 0.001$). Table 2 presents the pairwise comparison results of fracture resistance values. Based on the Tukey test, there were significant differences between the conventional composite group and the control group ($P = 0.0001$), Ribbond fiber ($P = 0.01$), and cuspal coverage groups ($P = 0.002$). The Angelus fiber group displayed a marginally significant difference compared to the conventional composite group ($P = 0.098$).

Figures 2 and 3 depict the frequencies and modes of favorable and unfavorable fractures in groups. According to Fisher's exact test, the differences in the frequency of favorable and unfavorable fractures across the groups were marginally significant ($P = 0.085$). Based on the Mann–Whitney test,

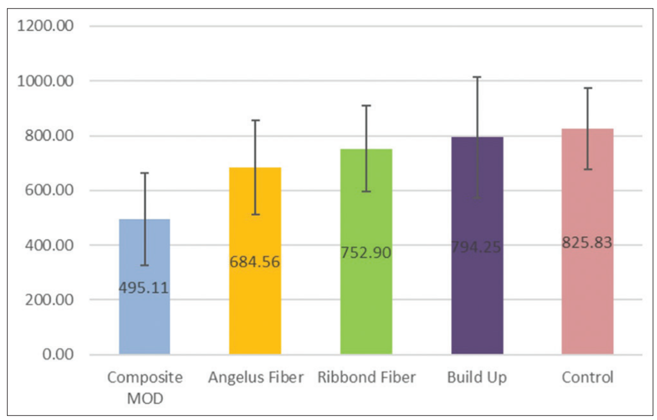

Figure 1: The mean fracture resistance values (Newton).

Table 2: Pairwise comparison results of fracture resistance values in Newton

Group 1	Group 2	*P*	SE	Mean differences
Control	Composite	0.001	74.59	330.71
	RF + composite	0.864	74.59	72.92
	AF + composite	0.334	74.59	141.26
	Restoration + composite	0.993	74.59	31.58
Composite	RF + composite	0.01	74.59	−257.79
	AF + composite	0.098	74.59	−189.45
	Restoration + composite	0.02	74.59	−299.13
RF + composite	AF + composite	0.889	74.59	68.33
	Restoration + composite	0.981	74.59	−41.34
AF + composite	Restoration + composite	0.586	74.59	−109.68

$P<0.05$ was the significance level. RF: Ribbond fiber; AF: Angelus fiber; SE: Standard error

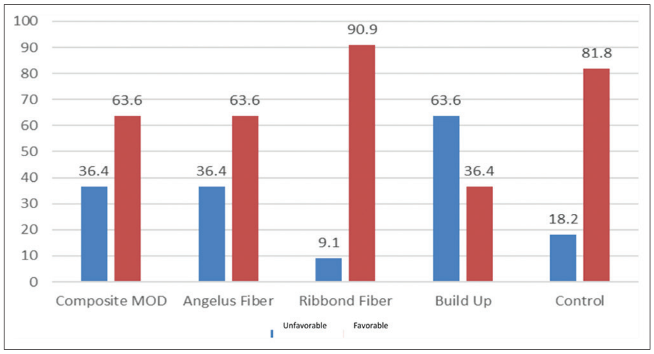

Figure 2: The frequencies of favorable and unfavorable fractures in groups.

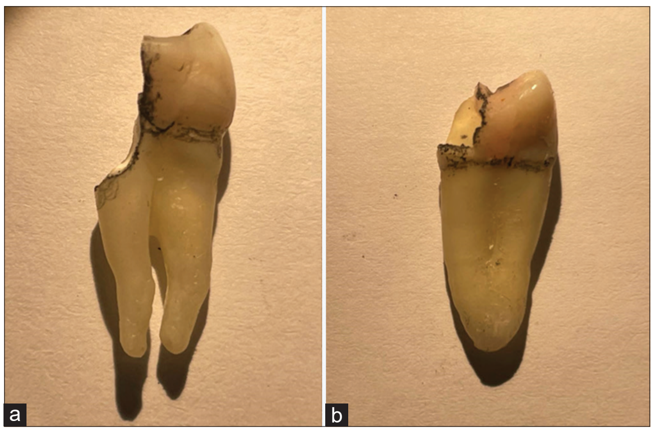

Figure 3: (a) Unfavorable fracture. (b) Favorable fracture.

significant differences were observed between the cuspal coverage group and the Ribbond group (*P* = 0.009) and also between the cuspal coverage group and the control group (*P* = 0.034).

In the ribbond group, the most fracture mode was favorable (90.9%), but in the buildup group, the unfavorable fracture frequency was higher. Furthermore, the most fracture mode in the control group was significantly different from the buildup group, and in the control group, the favorable fracture mode was the most one.In other cases, there were no significant differences among the groups.

DISCUSSION

This *in vitro* study aimed to evaluate the fracture resistance of resin composite restorations using various techniques in deep MOD cavities in maxillary premolars. According to the results, the null hypothesis was partially rejected. Composite restorations reinforced with fibers and cuspal reduction demonstrated a significantly higher fracture resistance compared to conventional composite restorations. In addition, fiber application and cuspal reduction were able to restore the fracture resistance of restored teeth to a level comparable to intact teeth.

The increase in height and narrowing of the cusps following preparation weakens the tooth's structure, making it susceptible to fracture.[22] The buccolingual width of the cavity significantly affects the fracture resistance of cusps, with MOD cavity preparation representing the least favorable scenario in terms of fracture resistance.[23,24] In maxillary premolars, the loss of a marginal ridge results in a 46% reduction in stiffness, while MOD cavity preparation results in an average 63% reduction in cuspal stiffness.[25] Therefore, in this study, MOD cavity preparation was used to simulate the worst-case clinical scenario.

Clinically, the natural bite force in the upper premolar area ranges from 222 to 445 N (average 322.5 N).[26,27] This suggests that all experimental groups in this study can withstand the functional loads in the oral cavity. However, as noted by Jafari Navimipour *et al*. in their study, it must be considered that certain clinical conditions, such as thermal changes, chemical factors, and fatigue stress from repetitive forces, may lead to restoration failure at much lower forces than their ultimate fracture resistance. Consequently, static load testing in laboratory settings may overestimate the fracture resistance of tested samples.[20] Various studies have highlighted the importance of simulating the periodontal ligament, as shown by Soares *et al*., who demonstrated that periodontal ligament simulation influences fracture resistance and fracture patterns,[28] an aspect that was included in this study.

The mechanical properties of restorations under masticatory loading and fatigue-induced fractures over time are crucial, which were addressed in this study to approximate about 5 months of clinical function.[3]

Despite significant advances in composite materials, polymerization shrinkage (ranging from 1.6% to 7.1%) remains a major limitation, creating contraction stresses that reduce fracture resistance and lead to restoration failure.[29] Incremental layering techniques are used to minimize these stresses.[4] Another inherent limitation of composites is their relatively low fracture toughness, which becomes especially evident in large composite restorations.[5] Based on these findings, conventional composite restorations alone may not be suitable for restoring posterior teeth with large MOD cavities, particularly in patients with parafunctional habits.

Fiber networks redirect stress at the restoration–adhesive interface, ultimately reducing the risk of unfavorable fractures. Fibers also displace part of the composite volume, thus reducing the amount of shrinkage.[11]

Various types of fibers are clinically available for reinforcing dental composites. Among them, ultra-high molecular weight polyethylene fibers and glass fibers are widely used in dentistry.[30]

The Ribbond Ultra fiber used in this study has a thickness of 0.12 mm, while the Angelus fiber is 0.25 mm thick. As observed in our study, the thinner fibers provide better cavity adaptation, easier handling, and greater clinical convenience.[31]

Agrawal *et al*. showed that applying polyethylene fibers to the pulpal and gingival floors significantly increased fracture resistance of composite restorations in maxillary premolars. In addition, they found that horizontal placement of fibers yielded better fracture resistance than vertical placement, as fibers oriented perpendicular to the applied force offered greater reinforcement.[6] In our study, fibers were also placed horizontally, which aligns with Agrawal *et al*.'s findings.[6] Similar results were observed in studies by Albar and Khayat[32]. Göktürk *et al*. found no significant difference in fracture resistance between conventional composite restorations with or without fibers.[33]

A systematic review by Jakab *et al*. on the effects of splinting with long fibers in deep MOD cavities indicated that out of 11 studies reviewed, 7 reported increased fracture resistance with horizontal splinting, consistent with our study's findings. Of the remaining studies, 3 reported no significant difference, and only one study noted lower fracture resistance in fiber-splinted restorations compared to conventional composite restorations.[25]

Research on glass fibers is less extensive than on polyethylene fibers. Tentardini Bainy *et al*. concluded that glass fibers increase fracture resistance in restored endodontically treated teeth regardless of formulation, corroborating our findings with the use of Angelus glass fibers.[34] Shadman *et al*. also confirmed that while glass fibers enhance fracture resistance, their effect is highly dependent on placement location within the restoration—a phenomenon not observed with polyethylene fibers, possibly due to differences in thickness and adaptability.[4]

In a study conducted by Khan *et al*., higher fracture strength in restorations reinforced with fiberglass compared to conventional resin composite restorations was confirmed.[30] However, Bahari *et al*. observed in a similar study that the fracture strength of teeth reinforced with fiberglass showed no significant difference compared to resin composite restorations and intact teeth because of similar von Mises stress distribution characteristics at restorative material–tooth interface of the groups and also it can be because of static applied forces in the study, which it cannot be a good substitute for dynamic fatigue test, the gold standard for the evaluation of fatigue, due to the effect of oral movements on tooth restorations.[35]

Deep MOD cavities often create long buccal and lingual walls that are prone to flexure and fracture. Some studies suggest that cusp coverage may be necessary to prevent failure of these remaining walls in such cavity types.[25]

In the present study, the highest numerical fracture strength values were observed in composite restorations with cusp coverage, showing a significant difference compared to conventional composite restorations.

Magne and Belser also documented a significant difference in fracture strength values between teeth restored with and without cusp coverage, highlighting the importance of cusp coverage.[36]

In the present study, polyethylene fibers showed a significant difference in fracture strength compared to the conventional composite group, and this difference was marginally significant in the comparison between glass fibers and conventional composite. However, no statistically significant difference was observed between the Ribbond and Angelus fiber groups.

Shadman *et al*. concluded that both types of fibers increased the fracture strength of teeth compared to conventional resin composite restorations; however, this increase in fracture strength for glass fiber-reinforced groups (unlike polyethylene fibers) was highly dependent on fiber placement. In groups where glass fiber was placed circumferentially in the cavity, the increase in fracture strength was similar to that of the polyethylene fiber group.[4]

In a study conducted by Khan *et al*. in 2018, the fracture strength of teeth restored with polyethylene (Ribbond) and glass (EverStick C and B) fibers was evaluated. Both polyethylene and glass fiber groups showed increased strength compared to teeth restored with resin composite alone; however, fracture strength values were higher in restorations reinforced with glass fibers than those with polyethylene fibers. This difference is likely due to issues in manually wetting Ribbond fibers, leading to the formation of bubbles in the matrix that weaken the structure and cause premature failure in restorations.[30]

This study also analyzed the fracture pattern of the restorations. The highest incidence of unfavorable fractures was observed in the cusp coverage group, which was statistically significant compared to the control and polyethylene fiber groups.

When a tooth can distribute applied forces effectively, a favorable fracture pattern is more likely. However, when a tooth is weakened by previous damage, masticatory or traumatic forces are more readily transferred and concentrated in the root area. Under these conditions, when failure occurs due to localized force concentration, the fracture line may extend into the root.[33] Consequently, at higher fracture strength values, the fracture pattern shifts from favorable to unfavorable, making the restoration non-restorable in a clinical setting.[37]

Seow *et al*. reported that in full-coverage restorations under load, stress propagates along the interface between the cusps, which may explain the higher incidence of unfavorable fractures in cusp-coverage restorations.[38]

The use of fibers to reinforce restorations enables stress distribution similar to that in healthy teeth. In the present study, 90.9% of fractures in the polyethylene fiber group were favorable, indicating that the fiber effectively directed applied forces beneficially. The positive effect of fibers in promoting favorable fracture patterns has been confirmed in other studies as well. Notably, the similar performance of polyethylene and glass fibers had not been previously studied or compared in nonroot-treated premolars.

CONCLUSION

The results of this study demonstrated that:

1. Fracture resistance in cuspal coverage and fiber-reinforced groups (both polyethylene and glass) did not significantly differ from that of intact teeth and was substantially higher than in the conventional composite group
2. No statistically significant difference was observed between the two fiber types (polyethylene vs. glass)
3. In terms of fracture patterns, the cuspal coverage group showed a significant difference from both the control and polyethylene fiber groups. The cuspal coverage group predominantly displayed unfavorable fracture patterns, while favorable fracture patterns were more common in the control and polyethylene fiber groups.

Recommendations

Future studies should explore various fiber orientations and lengths, with supplemental finite-element analyses to further optimize fiber placement strategies in composite restorations.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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