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Fracture resistance of pulpotomized primary molars restored with three types of composite resins with and without fiber-reinforcement

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Abstract

Objective: Coronal restoration of pulpotomized primary molars plays a vital role in ensuring the long-term success of the treatment. This study aimed to evaluate the effect of fiber reinforcement on the fracture resistance of pulpotomized primary molars restored with flowable or paste bulk-fill composite resins in comparison to a conventional composite resin.

Methods: In this in vitro experimental study, 48 primary molars were randomly allocated into six groups (n=8). The teeth were pulpotomozed and restored with the following materials: Group 1: Conventional composite resin, Group 2: Fiber+ conventional composite resin, Group 3: Paste bulk-fill composite resin, Group 4: Fiber+ paste bulk-fill composite resin, Group 5: Flowable bulk-fill composite resin, and Group 6: Fiber + flowable bulk-fill composite resin. Fracture resistance was measured by a universal testing machine, and the type of failure was determined. Data were analyzed using two-way ANOVA and Tukey's post hoc test ($\alpha = 0.05$).

Results: The highest fracture resistance was observed in group 6, whereas the lowest was in group 1. Two-way ANOVA revealed that the fiber reinforcement significantly increased fracture resistance ($P<0.001$), whereas the type of composite resin had no significant effect on fracture resistance ($P=0.182$). Most failure modes were restorable, with no significant differences observed between groups ($P=0.06$).

Conclusions: Under the study conditions, fiber reinforcement significantly improved the fracture resistance of pulpotomized primary molars. No significant differences were observed among the three composite resins or in their fracture patterns, implying that the three types of composite resins are suitable for restoring pulpotomized primary molars.

Keywords: Composite resin, Dental restoration, Fiber-reinforced composite, Fracture resistance, Primary dentition, Tooth fractures

Introduction

Primary teeth play a vital role as natural space maintainers, preserving dental arch integrity and supporting proper occlusal development (1, 2). After pulpotomy in primary molars, the loss of tooth structure reduces fracture resistance, making teeth more susceptible to fractures (3, 4). The overall strength of pulpotomized teeth depends on factors such as the amount of remaining tooth structure, the restorative material used, and the technique employed for restoration (5).

Various materials are available for restoring pulpotomized primary molars, including amalgam, stainless steel crowns, glass ionomers, composite resins, and compomers (6). Clinically, material selection is guided by cost-effectiveness and evidence-based approaches, with a preference for materials that facilitate quick and efficient restorations (7, 8).

Conventional composite resin restorations are commonly used in pediatric dentistry due to their favorable properties, including enhanced fracture resistance of restored teeth (9). However, these restorations require an incremental placement technique to manage polymerization shrinkage, which can be time-consuming, especially when treating uncooperative pediatric patients (10-12).

Bulk-fill composite resins can be applied in 4–5 mm increments and cured in a single step, simplifying the restorative procedure and potentially reducing clinical time (13, 14). This type of composite resin often exhibits

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higher wear rates and lower surface hardness compared to conventional composite resins (15).

A recent advancement in restorative dentistry is the introduction of flowable bulk-fill composite resins. This type of composite resin was designed to combine the benefits of flowable composite resins with the ability to be placed in thicker increments. These materials have low viscosity, allowing for easy adaptation to cavity walls, and they can be placed in a single layer, reducing the need for multiple applications. Although flowable bulk-fill composite resins offer improved depth of cure compared to traditional flowable composite resins, their mechanical strength and wear resistance may still be lower in stress-bearing areas (16).

The limitations of current composite resins in high-stress areas have driven researchers to explore new techniques such as fiber reinforcement (17). Fibers which are thin, high-strength strands of glass or other materials, are incorporated into a polymer resin matrix to improve mechanical properties (18). Some studies have suggested that fiber-reinforcement improved restorative performance in extensive mesial–occlusal–distal (MOD) cavities by reducing polymerization shrinkage stress and enhancing fracture resistance (19, 20). Various types of fibers, such as polyethylene and glass fibers, can be used to enhance the mechanical properties of composite resins by increasing strength, flexibility, and resistance to crack propagation (21). Additionally, fiber-reinforcement is considered cost-effective and has been shown to increase the fracture resistance of teeth undergoing root canal treatment (22-24).

Several studies assessed the impact of fiber reinforcement on the fracture resistance of bulk-fill composite resins in permanent teeth (9, 25, 26), but research focusing on primary teeth remains limited. The enamel structure of primary teeth differs from that of permanent teeth, characterized by lower calcium and phosphate concentrations, reduced thickness, and a unique orientation of cervical enamel rods. These structural differences may influence the performance of adhesive systems in primary teeth (27). There is also little evidence about the effects of flowable bulk-fill composite resins on the fracture resistance of primary teeth.

Therefore, this study aimed to evaluate the effect of fiber reinforcement on the fracture resistance of pulpotomized primary molars restored with three types of composite resins (paste bulk-fill, flowable bulk-fill, and conventional composite resin). The study's null hypothesis stated that there would be no difference in the fracture resistance of pulpotomized primary molars restored with three types of composite resins, regardless of the presence or absence of fiber reinforcement.

Materials and methods

Study design

This in vitro experimental study was conducted on 48 freshly extracted human primary second molars. The study protocol was approved by the ethics committee of Shahid Sadoughi University of Medical Sciences (IR.SSU.REC.1400.147), and informed consent was obtained from the parents or guardians of the children for the donation of extracted teeth for research purposes.

Sample size calculation

The sample size was determined using PASS software (PASS 15, NCSS, LLC, Kaysville, UT, USA). Based on the findings of a previous study (28), which reported a standard deviation of 57.18 for fracture strength in the fiber-reinforced bulk-fill composite resin group (the largest standard deviation observed), and assuming a 95% confidence level, 80% statistical power, and a minimum expected difference of 80 units in mean fracture strength between groups, the required sample size was calculated as eight specimens per group.

Sample selection and preparation

The study included 48 healthy primary second molars with intact buccal and lingual surfaces and at least one-third of the root length preserved. Teeth exhibiting caries, fractures, or visible cracks were excluded. Following soft tissue removal using a hand scaler, the teeth were stored in 0.5% chloramine T solution at 4°C for 72 hours, then transferred to distilled water until use.

Each tooth was vertically embedded in self-curing acrylic resin (Acropars, Tehran, Iran) within a Teflon mold, up to 1 mm below the cementoenamel junction (CEJ), ensuring the long axis was perpendicular to the mold base (28).

The teeth were randomly assigned to six groups (n = 8), based on the material used for final restoration. In all groups, standard mesial-occlusal-distal (MOD) cavities were prepared (Figure 1A) using a diamond bur (#245 Teezkavan, Tehran, Iran) with a diameter of 1 mm and length of 4 mm, operated in a high-speed handpiece under water coolant. Each bur was used for up to five teeth. The occlusal isthmus width was set to one-third of the intercuspal distance, and the proximal box width was two-thirds of the buccopalatal dimension. The cavity dimensions were verified with a graduated periodontal probe. The gingival floor was positioned 1 mm above the CEJ, with cavosurface margins prepared at a 90° angle. Subsequently, standard endodontic access cavities were created, and the coronal pulp tissue was removed.

The pulp chamber floor was uniformly filled with a layer of Zonalin cement (Zoliran, Golchadent, Tehran, Iran). The Zonalin was then covered with an approximately 0.5 mm layer of light-cured glass ionomer (LC GC Fuji II; GC, Tokyo, Japan), which was cured for 20 seconds using an LED light-curing unit with an intensity of 850 mW/cm² (Woodpecker Medical Instrument, Guilin, China). The curing light's intensity was verified before curing the teeth in each group to ensure consistent polymerization.

After curing the glass ionomer layer, a periodontal probe was used to confirm that the distance between the margin and the cavity floor was at least 4 mm, ensuring sufficient depth for the subsequent composite placement. Teeth that did not meet this criterion were excluded from the study. A Tofflemire metal matrix (0.05 mm thick; Kerr Hawe SA, Bioggio, Switzerland) was secured around the tooth using a matrix holder. Selective acid etching was performed with 37% phosphoric acid gel (FGM, Santa Catarina, Brazil) for 15 seconds on dentin surfaces and 30 seconds on enamel margins, followed by rinsing for 30 seconds. The bonding agent (Ambar Universal APS; FGM) was gently applied with a micro-brush and rubbed for 10 seconds, followed by a second bonding agent application for another 10 seconds. The cavity surfaces were then gently air-dried for 10 seconds and light-cured for 20 seconds.

Tooth restoration in the study groups

The 48 teeth in the six study groups were restored with various composite resin materials as follows (Figure 1B):

Group 1 (Conventional composite resin; positive control): In this group, A 1 mm layer of flowable composite resin (Opallis; FGM) was placed over the glass ionomer and light-cured for 20 seconds. The cavity was then restored using conventional nanohybrid composite resin (Opallis; FGM) applied in increments with a maximum thickness of 2 mm per layer. Each increment was light-cured for 40 seconds.

Group 2 (Fiber + conventional composite resin): A 1 mm layer of Opallis flowable composite resin was applied over the glass ionomer. Before light-curing, a fiberglass woven strip (Interlig; Angelus, Londrina, PR, Brazil) measuring 2 mm × 4 mm was cut, impregnated with uncured resin, and then positioned mesiodistally within the uncured flowable composite resin. The assembly was then co-cured for 20 seconds. The cavity was restored using conventional Opallis nanohybrid composite resin in increments of up to 2 mm thickness, with each increment light-cured for 40 seconds.

Group 3 (Paste bulk-fill composite resin): A 1 mm layer of flowable composite resin (Opallis; FGM) was placed over the glass ionomer and light-cured for 20 seconds. The remaining cavity was filled in a single increment using a paste bulk-fill composite resin (Opus Bulk Fill APS; FGM) with a thickness of approximately 4 mm. The layer was light-cured for 40 seconds.

Group 4 (Fiber + paste bulk-fill composite resin): The same protocol as group 2 was followed. A fiberglass woven strip was impregnated with uncured resin and placed mesiodistally within a 1 mm layer of flowable composite resin (Opallis; FGM). The assembly was co-cured for 20 seconds. The remaining cavity was then restored with Opus Bulk Fill APS composite resin in a 4 mm increment and cured for 40 seconds.

Group 5 (Flowable bulk-fill composite resin): A 3 mm layer of a flowable bulk-fill composite resin (Opus Bulk Fill Flow APS; FGM) was applied and light-cured for 40 seconds. Subsequently, the remaining 1 mm of the cavity was filled with Opus Bulk Fill APS and cured for 20 seconds.

Group 6 (Fiber + flowable bulk-fill composite resin): A 1 mm layer of Opus Bulk Fill Flow composite resin was applied over the glass ionomer. Before light-curing, a fiberglass woven strip was cut to dimensions of 2 mm × 4 mm, impregnated with uncured resin, and placed mesiodistally into the uncured flowable composite resin. The assembly was then co-cured for 20 seconds. Then, the cavities were restored with a 3 mm layer of Opus Bulk Fill Flow APS composite resin and cured for 40 seconds. The rest of the cavity was filled with Opus Bulk Fill APS and cured for 20 seconds.

To ensure complete polymerization, the teeth in all groups received an additional 20-second light curing from both the mesial and distal sides after removal of the matrix strip.

The specimens were then stored in distilled water at 37°C for two weeks. Subsequently, thermocycling was performed using a thermocycling machine (Delta Tpo2, Nemo, Mashhad, Iran), and the teeth were subjected to 1,000 cycles between 5°C and 55°C, with a dwell time of 30 seconds and transfer time of 5 seconds (Figure 1C).

Fracture resistance testing

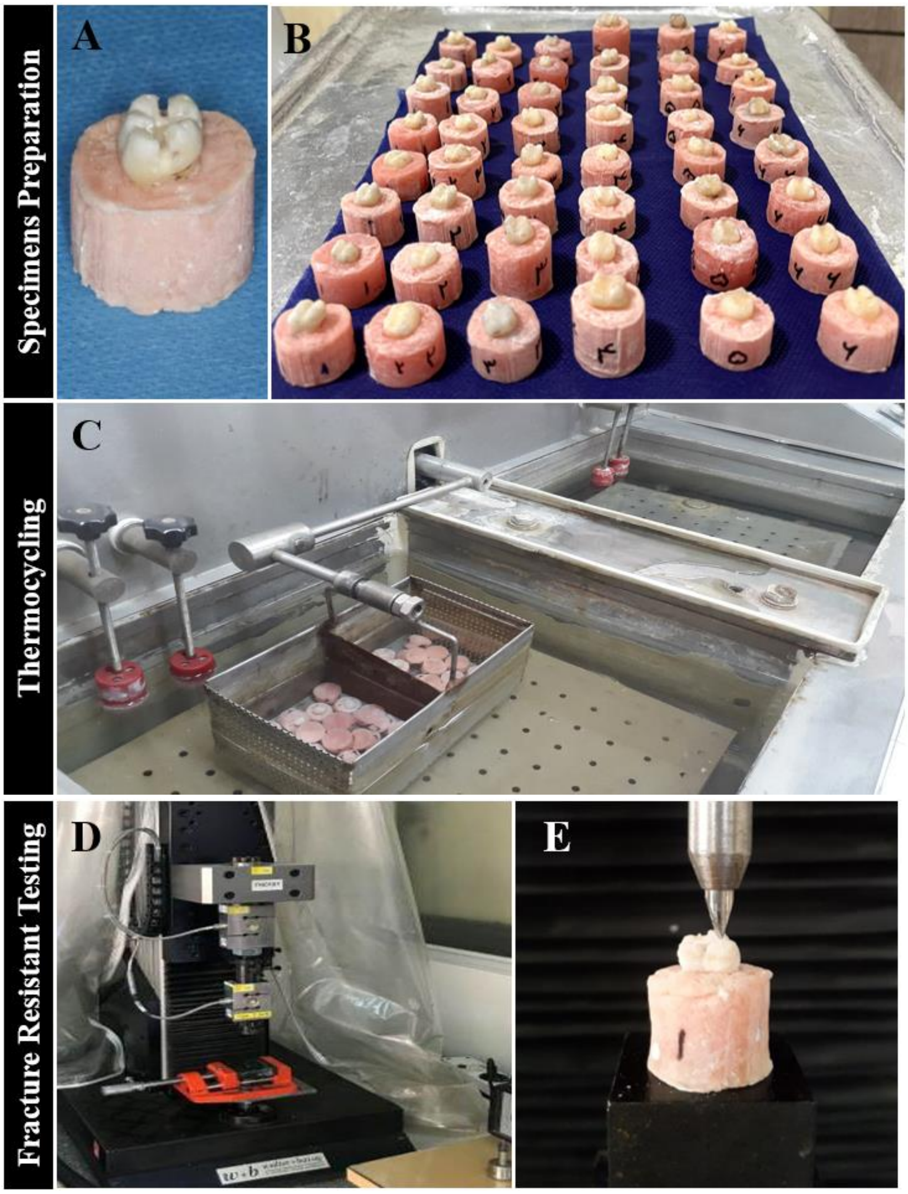

Figure 1. A. Preparing a standard MOD cavity, B. Restored specimens, C. The thermocycling machine, D. The universal testing machine, E. A specimen under fracture testing

The fracture resistance of the specimens was measured using a universal testing machine (K–21046, Walter + Bai, Löhningen, Switzerland) (Figure 1D). A compressive load was applied via a 4 mm diameter stainless steel tip at a crosshead speed of 1 mm/min, positioned perpendicular to the long axis of the tooth. The tip contacted both the buccal and lingual cusps simultaneously until fracture occurred (Figure 1E). The maximum force at fracture, identified by a sudden drop in the load-displacement curve, was recorded in Newtons (N).

Failure mode assessment

To analyze failure modes, fractured specimens were examined under a stereomicroscope (SMP 200, HP, USA) at 16 × magnification. Fractures were classified into restorable and non-restorable categories based on the location of the fracture line relative to the cementoenamel junction (CEJ):

Fracture type 1 (Restorable): The fracture line was located above the CEJ.

Fracture Type 2 (Restorable): The fracture line was located at the level of the CEJ.

Fracture Type 3 (Non-restorable): The fracture line was situated below the CEJ.

The representative samples of restorable and non-restorable fractures are illustrated in Figure 2.

Statistical analysis

The data were analyzed using IBM SPSS Statistics software, version 25.0 (IBM Corp., Armonk, NY, USA).

Table 1. The mean and standard deviation (SD) values of fracture resistance (N) in the study groups

	Without Fiber	With Fiber	Total
	Mean ± SD	Mean ± SD	
Conventional composite resin	602.8 ± 208.8	889.4 ± 294.6	746.1 ± 287.7
Paste bulk fill composite resin	611.7 ± 352.7	695.5 ± 253.0	653.6 ± 299.7
Flowable bulk-fill composite resin	691.7 ± 234.8	909.6 ± 291.4	800.7 ± 279.3
Total	635.4 ± 263.8	831.5 ± 285.4	
The effect of composite resin type	0.325		
The effect of fiber insertion	0.018		
Interaction effect	0.578		

The normal distribution of fracture resistance data was confirmed using the Shapiro–Wilk test (P > 0.05). A two-way analysis of variance (ANOVA) was performed to evaluate the effects of composite resin type and fiber reinforcement on the fracture resistance of pulpotomized primary molars. Statistical significance was set at P < 0.05.

Results

Table 1 shows the mean and standard deviation (SD) of fracture resistance values (in Newtons) in the study groups. The fiber-reinforced flowable bulk-fill composite resin (group 6) exhibited the highest mean fracture resistance (909.6 ± 291.4 N), whereas the conventional composite resin without fiber reinforcement (group 1) demonstrated the lowest mean value (602.8 ± 208.8 N).

The two-way ANOVA revealed that the type of composite resin had no significant effect on the fracture resistance of primary molars (P = 0.325), but fiber reinforcement had a statistically significant effect (P = 0.018). The interaction between the composite resin type and fiber reinforcement was not significant (P = 0.578; Table 1).

Table 2 presents the frequency and percentage of different failure modes in the study groups. In all groups, restorable fractures occurred more frequently than non-restorable fractures. In the conventional composite

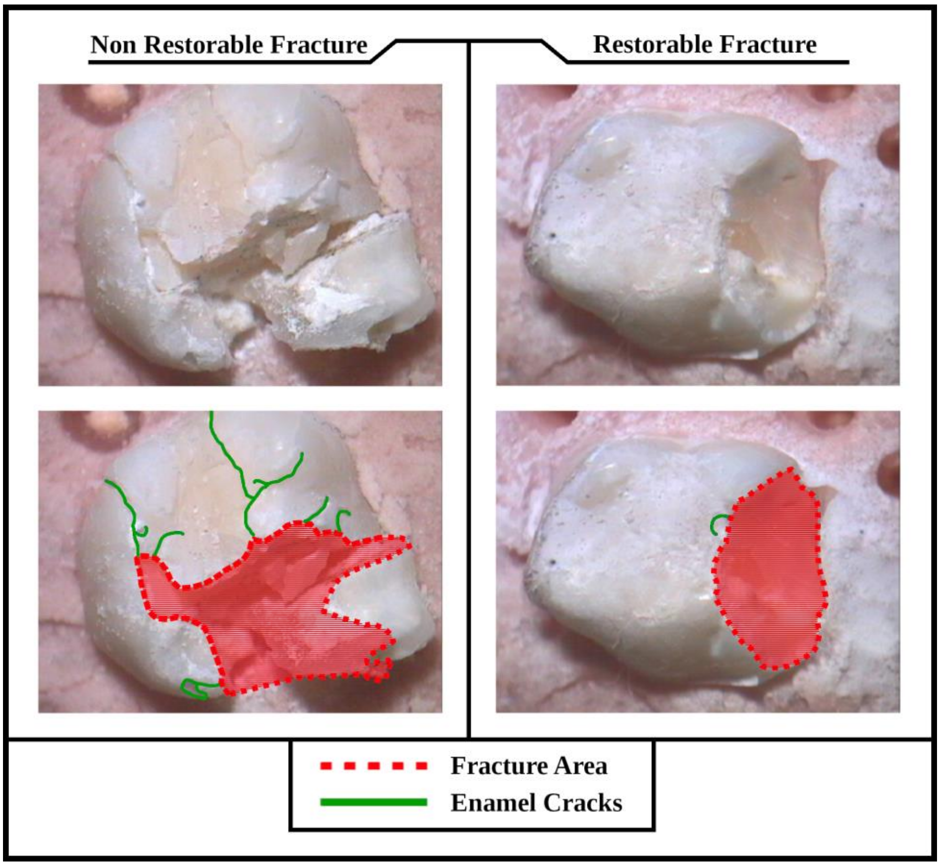

Figure 2. Representative samples showing restorable and non-restorable tooth fracture patterns

Table 2. The frequency and percentage (%) of different failure modes in the experimental groups

Group	Without fiber		With fiber	
	Restorable (%)	Non-restorable (%)	Restorable (%)	Non-restorable (%)
Conventional composite resin	4 (50)	4 (50)	8 (100)	0 (0)
Paste bulk-fill composite resin	7 (87.5)	1 (12.5)	8 (100)	0 (0)
Flowable bulk-fill composite resin	6 (75)	2 (25)	6 (75)	2 (25)

resin without fiber reinforcement, restorable and non-restorable failures occurred at the same rate (50% each). When fiber reinforcement was added to the conventional composite resin, no non-restorable failures were observed. However, Fisher's exact test showed that the differences in failure modes among the groups were not statistically significant (P = 0.06).

Discussion

This study assessed the fracture resistance of pulpotomized primary second molars restored with three types of composite resins, with and without fiber reinforcement. The results showed no significant difference in fracture resistance among the composite resin types. However, the use of fiber-reinforcement significantly improved fracture strength compared to non-fibre-reinforced groups.

The present results are consistent with several studies that found no statistically significant differences in fracture resistance between bulk-fill and conventional composite resins in permanent teeth (29-32). In contrast, Keskin et al. (33), Malekafzali et al. (34), and Taha et al. (4) observed that bulk-fill composite resins exhibited significantly higher fracture resistance compared to conventional composite resins. Rosa de Lacerda et al. (35) demonstrated that condensable bulk-fill composite resins exhibit superior properties, which are attributed to their higher filler weight percentage. Several factors may contribute to the inconsistent findings across studies, including variations in tooth type and morphology, the bonding agent used, the composite resin formulation, the polymerization technique, and the amount of remaining tooth structure after cavity preparation.

Although the present study did not find a statistically significant effect of composite resin type on fracture strength, the flowable bulk-fill composite resin had slightly higher fracture strength than both the conventional and the condensable bulk-fill composite resins. Flowable bulk-fill composite resins are well-suited for adapting to cavity walls and generally have lower porosity compared to layered conventional composite resins. Additionally, flowable bulk-fill composite resins can act as an intermediate stress-absorbing layer when covered by a condensable bulk-fill composite resin, which provides higher filler content and improved mechanical properties (36). In the present study, a condensable bulk-fill composite resin was used as the final coating layer over the flowable bulk-fill composite resin. Therefore, the slightly higher fracture resistance observed in the flowable bulk-fill group may be attributed to the combined advantages of both flowable and condensable bulk-fill composite resins. A flowable bulk-fill composite resin with a condensable bulk-fill cover layer may be recommended for pediatric dentistry, as it offers improved cavity adaptation, reduced chair time, and ease of placement.

The present study found that the use of fiber significantly increased fracture strength compared to restorations without fiber reinforcement. A slight change in the position and orientation of the fiber within the composite resin can significantly influence the fracture resistance and failure mode of the restored tooth (28). In this study, the fiber was carefully placed in the mesiodistal direction on the cavity floor. Angelus glass fiber strips were used; these contain nanofillers that further enhance the fracture resistance of restored teeth.

The results of the present study align with those reported by Shafiei et al. (29), who observed enhanced fracture resistance with fiber reinforcement in conventional and flowable bulk-fill composite resins, but not in the paste bulk-fill composite resin. The lower value observed in the paste bulk-fill group was attributed to weak interfacial bonding and potential gap formation within the bulk layer. In contrast, the current study demonstrated benefits from fiber reinforcement in the paste-like bulk-fill composite resin. Additional discrepancies between the studies may stem from the morphological differences between primary and permanent teeth, the brand and type of composite resin and fiber used, restoration techniques, and fiber placement direction and position. The outcomes of this study are also consistent with those of Zareiyan et al.

(28), who reported that the fracture resistance of fiber-reinforced conventional composite resin was significantly higher than that of the conventional composite resin without fiber reinforcement. Similarly, Kumar et al. (37) reported that fiber reinforcement improved the average fracture resistance of composite resin restorations.

The increased fracture strength observed in fiber-reinforced restorations may be attributed to the splinting effect of the fibers, which connect and stabilize the cusps (25). The fibers form a stress-absorbing, shock-dampening complex at the fiber-resin interface, which prevents crack initiation and propagation. When a fiber within the mesh becomes distorted, the stress is transferred to adjacent intact fibers as well as the polymer matrix of the composite resin, thereby reducing the stress transmitted to the tooth structure and inhibiting crack progression. Additionally, the presence of fibers replaces a part of the composite resin volume, reducing polymerization shrinkage and the associated shrinkage stress within the restoration (38, 39).

In the present study, no significant differences were observed in the failure modes across the groups. Similarly, Scotti et al. (40) reported no significant differences in failure modes between fiber-reinforced and conventional composite restorations. In contrast, Mohammadipour et al. (20) observed a higher rate of restorable failure rates in fiber-reinforced restorations compared to conventional composite resin restorations in primary molars. These discrepancies may arise from variations in fiber type, fiber orientation, cavity depth, and loading angles across the studies.

A limitation of this study was the limited availability of suitable dental specimens. Additionally, the in vitro design of the study limits the generalizability of the findings. Future studies with larger sample sizes and in vivo designs are recommended to provide more comprehensive insights into the differences in fracture strength between various composite resins with and without fiber reinforcement.

Conclusions

Under the conditions used in this study:

1- The fiber placement, regardless of the composite resin type, significantly increased the average fracture resistance of pulpotomized primary second molars.
2- No significant differences were found in fracture resistance between the three composite resins (paste bulk-fill, flowable bulk-fill, and conventional composite resin). Therefore, all three types of composite resins were suitable for restoring pulpotomized deciduous molars in terms of fracture strength.
3- No significant difference was found in the type of fracture pattern among the study groups.

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None.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Z.B. contributed to the study design, supervision, and manuscript editing. F.F. contributed to the supervision and data collection. S.P. helped with data collection and analysis and wrote the manuscript. M.I. contributed to conceptualization, data analysis, and critical revision of the manuscript. All authors reviewed and approved the final version of the manuscript

Ethical considerations

The study protocol was approved by the ethics committee of Shahid Sadoughi University of Medical Sciences (IR.SSU.REC.1400.147), and informed consent was obtained from all patients for the donation of their extracted teeth for research purposes.

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