Cumhuriyet Dental Journal, 29(1): 129-137, 2026
DOI: https://doi.org/10.7126/cumudj.1805743

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 Publisher: Sivas Cumhuriyet Üniversitesi

Effect of Restorative Cavity Designs and Restoration Techniques on Fracture Resistance and Fracture Patterns in Simulated Immature Teeth: An In Vitro Study

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Research Article

History

Received: 17/10/2025
Accepted: 25/02/2026

ABSTRACT

Objectives: This study evaluated the effects of different restorative techniques—direct composite, fiber post, and the Bioblock technique—on the fracture resistance and fracture patterns of simulated immature teeth with mesio-occlusal (MO) and single buccal cusp (SBC) cavity designs.

Materials and Methods: Seventy single-rooted mandibular premolars were selected. Ten teeth randomly assigned as the control group, while the sixty teeth were allocated into six groups according to cavity design (MO or SBC) and restorative technique (direct composite, fiber post, or Bioblock) (n = 10). To simulate immature apices, root canals were enlarged using Gates Glidden drills, followed by apexification with a 3-mm-thick MTA layer. All specimens then underwent fracture resistance testing. Fracture resistance were evaluated using ANOVA, while fracture pattern were analyzed with the chi-square. The statistical significance level was set at $\alpha = 0.05$.

Results: The lowest fracture resistance was observed in the SBC fiber post group, while the control group exhibited the highest values. All MO subgroups demonstrated significantly higher fracture resistance than the SBC subgroups ($p < 0.01$). No significant difference was found between the direct composite and Bioblock groups ($p > 0.05$); however, both exhibited significantly greater fracture resistance than the fiber post groups ($p < 0.01$). No significant differences were observed in fracture patterns among the groups ($p > 0.05$).

Conclusions: MO cavity designs provided greater fracture resistance compared with SBC designs. Fiber post restorations yielded the lowest resistance values, whereas direct composite and Bioblock techniques performed significantly better.

Keywords: Dental restoration, endodontically-treated, failures, mineral trioxide aggregate

Restoratif Kavite Tasarımlarının ve Restorasyon Tekniklerinin Simüle Edilmiş İmmatür Dişlerde Kırılma Direnci ve Kırılma Paternleri Üzerine Etkisi: In Vitro Çalışma

Araştırma Makalesi

Süreç

Geliş: 17/10/2025
Kabul: 25/02/2026

ÖZ

Amaç: Bu çalışma, farklı restoratif tekniklerin—direkt kompozit, fiber post ve Bioblock tekniği—mezio-okluzal (MO) ve tek bukkal kusp (SBC) kaviteli simüle immatür dişlerde kırılma direnci ve kırılma paternleri üzerindeki etkilerini değerlendirmiştir.

Gereç ve Yöntemler: Yetmiş tek köklü mandibular premolar diş seçilmiştir. On diş kontrol grubu olarak ayrılmış, kalan örnekler ise kavite tasarımı (MO veya SBC) ve restoratif teknik (direkt kompozit, fiber post veya Bioblock) esas alınarak rastgele altı deney grubuna (n = 10) dağıtılmıştır. İmmatür apeksleri simüle etmek için kök kanalları Gates Glidden frezleriyle genişletilmiş ve ardından 3 mm kalınlığında MTA tabakası ile apeksifikasyon yapılmıştır. Tüm örneklerde kırılma direnci testi uygulanmıştır. Kırılma direnci verileri tek yönlü varyans analizi (ANOVA) ile kırılma paterni verileri ise ki-kare testi ile değerlendirilmiştir. İstatistiksel anlamlılık düzeyi $\alpha = 0{,}05$ olarak belirlenmiştir.

Bulgular: En düşük kırılma direnci SBC fiber post grubunda gözlenirken, en yüksek değerler kontrol grubunda bulunmuştur. Tüm MO alt grupları, SBC alt gruplarına göre önemli seviyede daha yüksek kırılma direnci göstermiştir ($p < 0{,}01$). Direkt kompozit ve Bioblock grupları arasında anlamlı fark bulunmamıştır ($p > 0{,}05$); ancak her ikisi de fiber post gruplarına kıyasla önemli seviyede daha yüksek kırılma direnci sergilemiştir ($p < 0{,}01$). Gruplar arasında kırılma paternleri açısından anlamlı farklılık gözlenmemiştir ($p > 0{,}05$).

Sonuçlar: MO kavite tasarımları, SBC tasarımlarına kıyasla daha yüksek kırılma direnci sağlamıştır. Fiber post restorasyonlar en düşük direnç değerlerini verirken, direkt kompozit ve Bioblock teknikleri anlamlı derecede daha iyi performans göstermiştir.

Anahtar Kelimeler: Başarısızlıklar, diş restorasyonu, endodontik tedavili dişler, mineral trioksit agregat

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How to Cite: Önem Pekuz Ş, Sarı M, Tüfenkçi P. (2026) Effect of Restorative Cavity Designs and Restoration Techniques on Fracture Resistance and Fracture Patterns in Simulated Immature Teeth: An In Vitro Study. Cumhuriyet Dental Journal, 29(1): 129-137.

Introduction

Infection- or trauma-induced disruption of root development presents significant challenges in root canal treatment.[1] In managing necrotic teeth with incomplete root formation, wide and irregular canals, thin dentinal walls, and the absence of an apical constriction complicate canal preparation, irrigation, and obturation. Consequently, attaining complete disinfection and a perfect seal of the root canatls proves to be difficult.[2]

The biomechanical behavior of teeth that have undergone endodontic treatment is affected by multiple factors, notably hard tissue loss due to caries, cavity preparation, canal instrumentation, and fractures.[3] Additionally, chemical agents used during chemomechanical preparation alter the organic and inorganic components of dentin, leading to decreased elasticity, flexural strength, and microhardness.[4]

The greatest reduction in tooth stiffness occurs following extensive cavity preparation, particularly when marginal ridges are lost. Specifically, occlusal restorative cavities have been reported to reduce fracture resistance by approximately 20%, whereas more extensive mesio-occluso-distal (MOD) restorative cavity preparations may decrease fracture resistance by as much as 63%.[3]

Long-term success in restoring endodontically treated teeth with significant structural loss relies on preserving healthy tooth tissue and ensuring sufficient retention for the coronal restoration. To achieve this, post-and-core restorations are frequently used, as they engage the root canal to provide both retention and reinforcement.[5,6] Fiber posts are often the material of choice because they combine favorable esthetic outcomes with a dentin-like elastic modulus, which helps minimize stress transfer to the root structure, while also allowing for core buildup in a single appointment.[7] Although placement of a crown over a post-and-core has traditionally been considered the standard approach, recent years have seen increasing use of direct composite resins and indirect restorations, for instance ceramic overlays or endocrowns, for the restoration of endodontically treated teeth.[8,9] When determining a restorative technique, the decisive factor is the volume of remaining tooth tissue, which plays a more pivotal role in long-term prognosis than the attributes of the restorative material itself.[10,11]

Another contemporary approach for restoring deep MOD cavities is the use of short fiber–reinforced composites (SFRCs).[5] Recommended as dentin substitutes in high–stress-bearing regions, SFRCs have been shown to improve fracture resistance and reduce the risk of catastrophic failure.[12] In 2019, a flowable SFRC was introduced, allowing easier adaptation to large cavities and difficult-to-access regions of the root canal. This material has demonstrated promising results both when used alone (the Bioblock technique) and as a luting agent.[13]

The aim of this study was to compare the effects of different restorative techniques—direct composite, fiber post, and the Bioblock technique—on the fracture resistance of simulated immature teeth restored with either mesio-occlusal (MO) or single buccal cusp (SBC) cavity designs. Previous studies have investigated reinforcement strategies for weakened roots; however, there is a lack of consensus on the most effective approach for simulated immature teeth, particularly when different restorative cavity configurations are considered. Moreover, limited evidence exists comparing the Bioblock technique with conventional methods such as fiber posts or direct composite restorations in this context. Therefore, this study addresses this gap by testing the null hypothesis that cavity design and restorative technique would not significantly affect the fracture resistance and fracture patterns of simulated immature teeth.

Materials and Methods

Sample size estimation was conducted using the GPower programme (v. 3.1.9.4). Seven different simulated tooth groups were created based on access cavity design and restorative technique. The sample size necessary to evaluate potential variations in fracture resistance among the groups was calculated based on a one-way ANOVA. Within ANOVA, Cohen's f effect size expresses the extent to which group means differ relative to standard deviation. Based on an effect size of 0.47,[10] a = 0.05, β = 0.80, the sample size was determined to be 70 teeth, with at least 10 specimens per group.

Ethical approval was obtained from the local ethics committee (decision no: 26, May 6, 2021).

Sample Preparation

Seventy single-rooted human mandibular premolars extracted within the previous six months for orthodontic reasons were used. Soft and hard tissue residues were eliminated using periodontal curettes. Following extraction, the teeth were stored in tap water, disinfected in 0.1% chloramine-T for a week.

Inclusion criteria required single-rooted teeth with a single, straight canal (<10° curvature, Schneider method). Selection of teeth with similar dimensions was based on buccolingual and mesiodistal measurements (Mitutoyo, Tokyo, Japan) at the CEJ, in addition to crown and root length assessments. Samples exceeding ±10% of the average values (5 mm mesiodistal, 7 mm buccolingual, 10.5 mm crown length, 14 mm root length) were excluded. Additional exclusion criteria included apical diameters larger than a #15 K-file, fractures, cracks, resorption, calcified canals, prior restorations, or previous root canal treatments, all of which were assessed under ×3.5 magnification (Zumax, Suzhou, China).

Group 1, serving as the control group, included ten randomly assigned teeth that were left without preparation or root canal filling.

Cavity Preparation

Sixty samples were randomly assigned into two groups based on restorative cavity configuration: MO and SBC (n = 30). Preparations were performed with a 014 diamond fissure bur (DIMEI, China) under copious water irrigation to ensure standardization. In MO designs, the occlusal isthmus corresponded to one-third of the buccopalatal crown dimension (≈3 mm), and the proximal box extended to two-thirds of this width. The gingival floor was set 1 mm above the CEJ. In contrast, SBC cavities were prepared by removing the lingual cusps to simulate large MOD designs. The cavity floor was leveled, with a 5 mm occlusal reduction, and the buccal wall preserved at an average thickness of 3 mm. Restoration margins were located about 1 mm coronal to the CEJ.

Root Canal Preparation

Following access to the canal orifices, a #15 K-file was used to establish the working length. The instrument was inserted into the canal until the tip emerged at the apical foramen, and the measurement was adjusted by withdrawing 1 mm.

Following glide path creation with a #15 K-file, 25/.08 and 40/.06 Reciproc files (VDW, Munich, Germany) were used sequentially with a 3-mm pecking motion and light apical pressure at the established working length. Canal preparation was performed using an X-SMART endodontic motor (Dentsply Maillefer) in Reciproc All mode, following the manufacturer's instructions.

Instrumentation was accompanied by irrigation with 2.5% sodium hypochlorite (NaOCl; Cermaked, Stalowa Wola, Poland), using a 30G side-vented needle (Navi Tip; Ultradent, South Jordan, USA), to a total volume of 15 ml. Between NaOCl and EDTA application, canals were flushed with 5 ml of distilled water. After preparation, the smear layer was removed with 5 ml of 17% EDTA (Coltene, Altstätten, Switzerland) for 1 minute, followed by a final rinse with 5 ml of distilled water. Drying was completed with paper points (Diadent Group International, Burnaby, BC, Canada). In all specimens, both the irrigation volumes and times were standardized.

The apical 3 mm of the roots was resected with a diamond bur to mimic immature apices, followed by sequential use of Gates Glidden drills (#1–6) extending 1 mm past the apex. Calcium hydroxide paste (UltraCal XS, Ultradent) was used to mimic clinical conditions, while the root tips were sealed with modeling wax (Cavex, Netherlands) in order to avoid paste extrusion.

Following placement of a cotton pellet, access cavities were sealed with Cavit (3M ESPE, Seefeld, Germany). The specimens were then incubated for 1 week at 37 °C under 100% humidity. Following the storage period, canals were irrigated with 15 ml of 2.5% NaOCl to remove the calcium hydroxide. An EndoActivator (EA; Dentsply, York, PA) with a 25/04 polymer tip was inserted 2 mm short of the working length and operated at 10,000 rpm for 1 minute to activate NaOCl. Activation of irrigation consisted of a 1-minute rinse with 5 ml of 17% EDTA, followed by a final flush with 5 ml of distilled water. Subsequently, canals were dried using paper points.

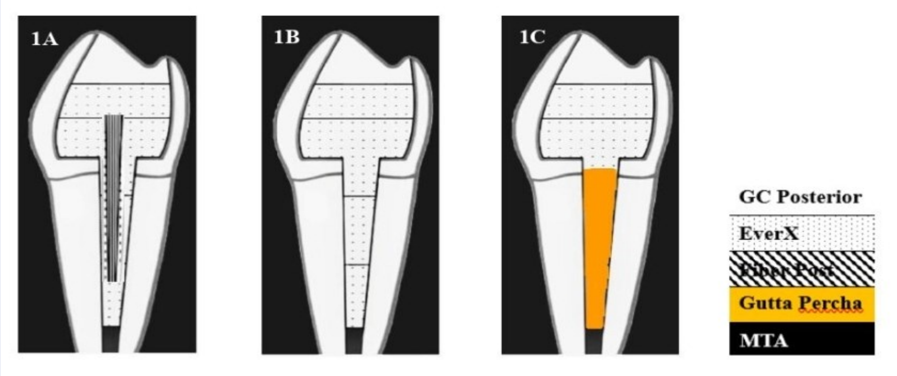

Figure 1. Figure 1 illustrates the endodontic and restorative procedures performed in the Fiber Post, Bioblock Technique, and Direct Composite Restoration Groups in both Mesio-Occlusal and Single Buccal Cusp cavity designs. 1A: Fiber Post; 1B: Bioblock Technique; and 1C: Direct Composite Restoration.

Root Canal Filling and Coronal Restoration

Mineral trioxide aggregate (MTA) was prepared on a glass slab with a metal cement spatula by mixing it with distilled water at a 1:1 ratio. The mixture was introduced into the root canals and condensed to a 3-mm apical thickness with a hand plugger. To ensure precise placement, a cotton pellet was positioned 3 mm coronal to the simulated apex. A moist gauze was placed over the remaining MTA on the glass slab to prevent dehydration during manipulation. Radiographs were taken to verify MTA positioning. Specimens were then wrapped in moist gauze and incubated for 48 hours at 37°C in 100% humidity.

Subsequently, AH Plus sealer (Dentsply Sirona, USA) was prepared on a glass slab. The master cone, a 40/.06 gutta-percha point (VDW, Munich, Germany) matching the final shaping file, was covered with sealer and inserted into the canal. Obturation was completed using the cold lateral condensation technique with a #30 spreader (Mani Inc.) and 25/.02 accessory gutta-percha cones.

Once obturation was completed, all specimens were subjected to random allocation into six groups, each group including 10 samples. Representative images of the groups are presented in Figures 1.A-C.

Group 2–MO Cavity Groups

Group 2a–Fiber Post Group

The preparation of post spaces was performed to a depth of 5 mm from the canal orifice employing size 1 burs (1.4 mm diameter) of the Cytec™ Blanco Post system (Hahnenkratt, Königsbach-Stein, Germany). An apical root filling of 5 ± 1 mm was preserved in the canals. Following application of Clearfil SE Bond Plus (Kuraray Medical Inc., Japan) to the post spaces, as per the manufacturer's instructions, Clearfil DC Core Plus (Kuraray Medical Inc.) was injected, and the Cytec™ Blanco post was coated with a thin layer of the same resin. The post was gently seated into the canal using finger pressure, after which the resin was light-cured (430–480 nm; 1200 mW/cm²; Elipar S10; 3M ESPE, St. Paul, MN, USA) for 40 seconds while maintaining the post in a vertical orientation. The curing light was positioned close the coronal cavity but without direct contact. To verify the light output, the average power density was measured using Jetlite light tester (Morita USA Inc., Irvine, CA, USA). Excess resin was removed using diamond burs under continuous water cooling.

For coronal restoration, a Tofflemire matrix band was positioned around each specimen. Short fiber–reinforced composite everX Posterior from GC Corporation (Tokyo, Japan) was incrementally applied in 2-mm layers. The material was then shaped with a hand instrument. A 1.5–2 mm space was preserved on the occlusal and proximal surfaces for final coverage with posterior composite (GC Posterior). Each coronal composite increment was polymerized for 40 seconds by applying light from the occlusal surface. Finishing and polishing were performed with polishing rubber points (Frank, Germany) (Figure 1A).

Group 2b–Bioblock Technique Group

Post space preparation and adhesive procedures were performed as described for Group 2a. A post-and-core build-up was then completed using SFRC. About 4-mm bulk fill of SFRC was placed into the post space, with the apical portion placed using an applicator. A light-transmitting Cytec™ Blanco fiber post (1.4 mm diameter) was inserted to facilitate light transmission to the apical composite layers. The post was then carefully withdrawn by approximately 0.5–1 mm in order to prevent direct contact with the unpolymerized SFRC. Each composite layer was polymerized for 40 seconds by transmitting light through the fiber post. This procedure was repeated until the root canal was filled to the CEJ level. Final restoration and adhesive procedures were performed as described for Group 2a (Figure 1B).

Group 2c–Direct Composite Restoration Group

Following cavity preparation and endodontic treatment, a Tofflemire matrix band was placed. The access cavities were dried with air spray, and Clearfil SE Bond Plus was applied. All cavity walls received the primer of the two-step self-etch adhesive for 20 seconds, followed by gentle air-drying for 5 seconds. The bond was then applied, air-thinned, and light-cured for 10 seconds. SFRC was then placed incrementally in 2-mm layers and polymerized for 40 seconds per increment. A 1.5–2 mm space was preserved at the occlusal and proximal surfaces for coverage with posterior composite, which was placed incrementally and light-cured for 40 seconds. Final finishing was performed with a yellow-banded flame-shaped bur, and polishing was completed using composite polishing rubber points (Figure 1C).

Group 3–Single Buccal Cusp (SBC) Groups

- Group 3a (Fiber Post): The procedures for endodontic treatment and coronal restoration were carried out as previously described for Group 2a.
- Group 3b (Bioblock): The procedures for endodontic treatment and coronal restoration were carried out as previously described for Group 2b.
- Group 3c (Direct Composite): Coronal restoration was carried out as previously described for Group 2c.

The specimens were maintained at 37 °C and 100% humidity for one week to ensure full polymerization of the restorative materials.

Mechanical Testing and Evaluation

The restored specimens were embedded in acrylic within custom-fit plastic holders. A load was applied from the central fossa in a lingual direction, parallel to the long axis of the tooth (Instron, Buckinghamshire, UK). Force was delivered with a 6-mm round-ended indenter at 1 mm/min until fracture occurred, defined as the final decline in the load–deflection curve. The fracture loads were measured and documented in Newtons (N).

Fracture patterns of the samples were also assessed. Following the protocol proposed by Scotti et al.[14] fractures were classified as restorable or non-restorable under an optical microscope. Fractures occurring above the CEJ were considered restorable, as they allow re-restoration, while those extending below the CEJ were classified as non-restorable, usually requiring extraction.

Statistical Analysis

Normality of the numerical variables was assessed by calculating skewness and kurtosis values. Homogeneity of variances was tested using Levene's test. Given that the data satisfied both normality and homogeneity assumptions, One-Way Analysis of Variance (ANOVA) was performed to compare the groups, while Duncan's Multiple Comparison Test was applied to determine intergroup differences. Fracture pattern data were analyzed using the chi-square test. Statistical significance was considered at levels of 0.05 and 0.01.

Results

Seven distinct simulated tooth groups were created according to restorative cavity design and restorative technique. A comparative summary of their fracture resistance values is presented in Table 1.

Fracture resistance differed significantly among the groups ($p < 0.01$). The lowest fracture resistance was recorded in the SBC fiber post group (295.11 N), whereas the highest was observed in the control group (974.08 N). All MO cavity subgroups exhibited significantly higher fracture resistance compared with the SBC subgroups.

Within the MO cavity groups, mean fracture resistance values ranked from lowest to highest were: MO fiber post (557.12 N), MO direct composite (751.48 N), and MO Bioblock (809.87 N). The MO Bioblock and MO direct composite groups did not differ significantly ($p > 0.05$), but both demonstrated greater fracture resistance than the MO fiber post group ($p < 0.01$).

Among the SBC groups, the ranking was: SBC fiber post (295.11 N), SBC direct composite (428.51 N), and SBC Bioblock (456.25 N). No difference was detected between the SBC Bioblock and SBC direct composite groups (p >

0.05); both exceeded the SBC fiber post group in fracture resistance ($p < 0.01$).

The distribution of fracture patterns did not differ significantly among groups ($p > 0.05$). Restorable fractures were recorded in 8 samples of the Bioblock group, 7 of the fiber post group, and 5 of the direct composite group. Unrestorable fractures occurred in 2, 3, and 5 samples, respectively (Table 2; Figure 2).

Table 1. Comparison of fracture resistance according to simulated tooth groups (N)

	Groups	n	Mean ± SD	Median	Min.	Max.
Control	Control	10	974.08 ± 176.58^{E}	944.18	719.80	1273.80
MO	Bioblock technique	10	809.87 ± 123.33^{D}	804.45	615.10	987.20
MO	Direct composite	10	751.49 ± 122.81^{D}	732.30	600.30	983.70
MO	Fiber post	10	557.12 ± 124.48^{C}	541.35	390.90	859.70
SBC	Bioblock technique	10	456.25 ± 55.12^{BC}	447.05	403.90	556.30
SBC	Direct composite	10	428.51 ± 79.11^{B}	419.70	339.80	554.80
SBC	Fiber post	10	295.11 ± 52.68^{A}	292.80	217.70	366.00

**$p < 0.05$, **$p < 0.01$, Lettering: Duncan Multiple Comparison Test.*
N: Values are expressed in Newtons.
MO: Mesio-occlusal; SBC: Single Buccal Cusp.

Table 2. Distribution of fracture types according to simulated tooth groups

Groups	Restorable		Non-Restorable		$p\chi^2$
	Count	%	Count	%	
Control	10	100.0	0	0.0	0.084
Bioblock Technique	8	80.0	2	20.0	
Fiber Post	7	70.0	3	30.0	
Direct Composite	5	50.0	5	50.0	

**$p < 0.05$, **$p < 0.01$, χ^2: Chi-square test (Categorical data).*

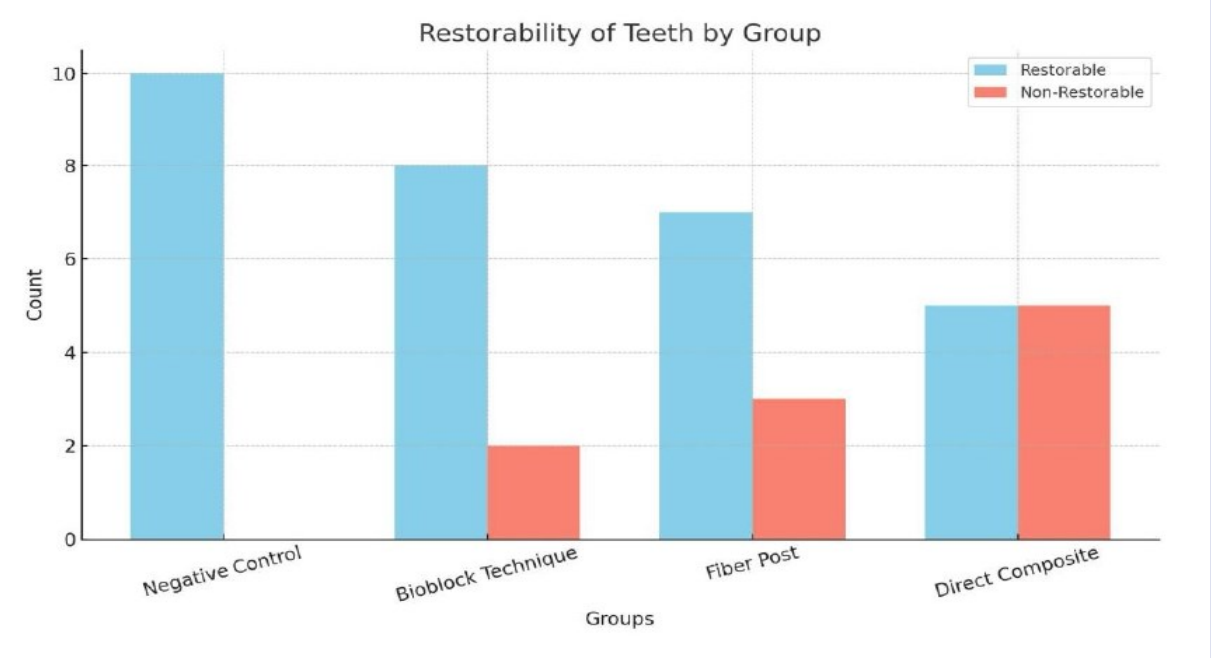

Figure 2. Figure 2 illustrates the distribution of fracture patterns across the simulated tooth groups.

Discussion

The preservation of immature teeth with extensive substance loss is essential for maintaining both esthetic and functional integrity of the masticatory system. However, thin residual root walls make these teeth prone to cervical third fractures.[15] Given the increased vulnerability of endodontically treated immature teeth to functional and external forces, reinforcement of the remaining tooth structure is of critical importance. Accordingly, the appropriate selection of restorative procedure capable of strengthening the tooth structure plays a pivotal role in achieving favorable long-term clinical outcomes.[16-18]

In the present study, the effect of various cavity designs and restorative techniques on the fracture resistance of immature teeth was evaluated. The findings revealed significant differences among the groups, leading to the rejection of the null hypothesis.

Traumatic dental injuries are known to affect maxillary anterior teeth with the highest frequency. However, in the present study, mandibular premolars were selected because of the difficulty in obtaining a sufficient number of extracted incisors. Mandibular premolars, which are more readily available due to their frequent extraction for orthodontic purposes, also provide advantages related to their single-rooted, single-canal anatomy. Open apices were simulated by resecting the apical 3 mm of the roots with a diamond bur, thereby removing apical deltas and standardizing root length to obtain root samples of uniform dimensions.[19]

Previous reports have indicated that immature tooth simulation using a #5 Gates Glidden drill (1.5 mm diameter) extended 1 mm beyond the apex may not sufficiently compromise the root structure and could be inadequate for producing clinically relevant differences among experimental groups.[20] To achieve a more effective and standardized apical simulation, a #6 Gates Glidden drill was therefore employed in this study.

In this study, fracture resistance values were significantly lower in SBC cavities compared with MO cavities, regardless of the restorative technique. Assif et al.[21] emphasized that the structural integrity of a tooth is primarily determined by the quantity and continuity of the remaining sound tooth structure. Deep MOD cavities are particularly susceptible to fracture due to the increased cavity volume and greater cuspal deflection resulting from marginal ridge loss. Moreover, cavity configuration, cavity depth, and isthmus width are pivotal elements influencing fracture resistance.[22-24] In maxillary premolars, fracture resistance has been shown to decrease by 53% when the isthmus width is one-third of the intercuspal distance, and by as much as 67% when it is one-half.[25]

Although MTA effectively establishes an apical barrier in immature teeth, it does not reinforce thin dentinal walls.[4] Previous studies have demonstrated that composite restorations alone do not improve cervical resistance, whereas intraradicular reinforcement with adhesive materials may enhance structural durability.[26,27] For this purpose, fiber posts or fiber-reinforced composite (FRC) posts have been proposed after apical barrier formation.[13]

In the present study, the fiber post group exhibited lower fracture resistance than both the Bioblock and direct composite groups. These findings are consistent with previous reports demonstrating that fiber posts do not reinforce immature teeth and may even predispose them to unfavorable fractures.[26,28-31]

In contrast, some studies have reported improved fracture resistance following fiber post placement. Crozet et al.,[32] and Schmoldt et al.[33] observed increased resistance in bovine teeth, while Tanalp et al.[15] suggested a reduction in cervical fracture incidence in decoronated teeth restored without coronal reconstruction. However, these divergent findings may be attributed to methodological differences, including the use of bovine versus human teeth, absence of coronal restoration, variations in apical simulation protocols, and differences in restorative materials and apical barrier thickness.

The inferior performance of fiber posts compared with Bioblock and direct composite restorations may be attributed to additional dentin removal during post space preparation, weakening of already thin root walls and stress concentration at the post–cement interface.[34] This effect is particularly pronounced in immature teeth with wide canals, where a mismatch between the post and the canal space can result in an excessively thick resin cement layer and the incorporation of air bubbles, thereby compromising the bond.[35] Previous studies on composite resin–restored teeth have demonstrated that fracture resistance is largely determined by the number of remaining coronal walls; in teeth with at least two intact walls, fiber posts provide no additional benefit.[36,37] Nevertheless, although fiber posts may not reinforce the root, they have been reported to positively influence fracture patterns by distributing occlusal stress. In cases with sufficient residual tooth structure, the contribution of posts to long-term survival is limited, and the potential risks associated with their use should be carefully weighed.[29,38]

To preserve structural integrity after endodontic treatment, intraradicular application of FRC or SFRC has been proposed as an alternative to fiber posts. In the Bioblock technique, packable SFRC (EverX Posterior) is applied directly to canal walls to form a monoblock structure, reinforcing the root without the need for a separate post or adhesive cement.[35,39]

Fráter et al.,[39] demonstrated that premolars with MOD cavities restored using the Bioblock technique exhibited greater fracture resistance than those treated with fiber posts, while Forster et al.[40] highlighted its potential to reinforce the pericervical region. Similarly, in simulated immature anterior teeth, Bioblock with flowable SFRC achieved survival rates comparable to intact teeth.[13]

Regarding material type, flowable SFRC used as a luting-core material with individually fabricated FRC posts showed fatigue survival comparable to intact teeth, whereas packable SFRC demonstrated lower survival.[13] This difference has been attributed to fiber composition: packable SFRC contains millimeter-long fibers, while flowable SFRC incorporates micrometer-scale fibers with a higher aspect ratio, potentially enhancing reinforcement and bonding to dental tissues.[41]

In the present study, no significant difference in fracture resistance was observed between the Bioblock and direct composite groups in either SBC or MO cavities. However, both groups exhibited significantly higher resistance compared with their respective fiber post groups. Similarly, Ayad et al.,[42] reported that Class II cavities restored with FRCs were more durable than those restored with conventional composites. Also, Eapen et al.,[43] demonstrated that SFRC significantly improved the fracture resistance of maxillary premolars with MOD design. The absence of difference between Bioblock and direct composite groups suggests that preservation of dentinal walls may be more critical than intraradicular reinforcement in teeth with at least partial coronal structure.

The primary purpose of fiber reinforcement in SFRCs is to preserve structural integrity and reduce the risk of fracture. The performance of this reinforcement relies on fiber type, length, orientation, and compatibility with the resin matrix. Fibers contribute by transferring functional stresses and acting as crack arresters. The primary purpose of fiber reinforcement in SFRCs is to preserve structural integrity and reduce fracture risk. Its effectiveness depends on fiber type, length, orientation, and compatibility with the resin matrix. Fibers enhance mechanical performance by transferring functional stresses and acting as crack arresters,[44,45] as demonstrated by Garoushi et al.[12] who reported that short fibers effectively inhibit crack propagation and improve fracture resistance In dual-cure resins used for intraradicular cementation, polymerization shrinkage stress and void formation are major concerns due to the high configuration factor (C-factor).47 In contrast, fiber orientation in SFRCs helps mitigate shrinkage stress.[46] SFRC does not shrink along the fiber axis and maintains its horizontal dimensions; although shrinkage may occur within the surrounding polymer matrix, this characteristic improves adaptation to canal walls and enhances reinforcement.[39]

In the Bioblock technique, SFRC adapts to the dentinal walls, thereby removing associated drawbacks associated with the biomechanically unfavorable placement of adhesive cement and fiber posts.[39] This approach reduces the impact of deleterious forces generated during restoration and aims to prevent biomechanical complications at both the post–cement and cement–canal wall interfaces.[47]

In the present study, no significant differences in fracture patterns were detected among the groups. Fráter et al.,[39] reported that although dual-cure composite resin and SFRC did not differ significantly in fracture resistance, they exhibited distinct fracture patterns. In their study, irreparable fractures were predominant in teeth restored with FRC posts and conventional composite, whereas more favorable, restorable fractures were observed in groups restored with SFRC. This outcome has been attributed to the weak adhesion of FRC posts and the inadequate bonding of the epoxy-based matrix to composite resin or tooth tissue. In contrast, SFRC appears to modify fracture behavior toward a more restorable pattern due to its stress-absorbing properties. This reinforcing effect is closely related to the integration of fibers within the polymer matrix and the achievement of critical fiber length.[48,49]

In our study, static vertical loading was applied to the specimens. Although teeth are subjected to repetitive, low-intensity stresses under functional conditions, static tests remain valuable for assessing fracture behavior and load-bearing capacity, given the linear correlation between static loading and fatigue behavior. Taha et al.[50] and Le Bell-Rönnlöf et al.,[36] confirmed that static testing provides a robust approach to analyze restorative materials and cavity designs. Nevertheless, a limitation of this study is that only static loading was evaluated. Future investigations should incorporate dynamic loading conditions to more closely simulate clinical function.

Thermal cycling is a widely used in vitro method aimed at aging the adhesive interface between restorative materials and tooth structure by simulating temperature fluctuations encountered in the oral environment. Repeated thermal stresses acting on materials with different coefficients of thermal expansion may compromise adhesive bonding and alter the mechanical behavior of the restoration–tooth complex.[51] The simulation of the periodontal ligament is another important factor influencing fracture strength values. The periodontal ligament mimics the physiological mobility of the tooth and plays a significant role in stress distribution as well as in the initiation and propagation of fractures. Previous studies have demonstrated that omitting artificial periodontal ligament simulation during loading tests may result in fracture resistance values nearly twice as high as those obtained when periodontal simulation is performed.[52,53] However, in the present study, thermal cycling and periodontal ligament simulation were not performed. Therefore, the repetitive and dynamic nature of masticatory forces, the cushioning effect of the periodontal ligament, and the influence of oral environmental factors—such as moisture, pH fluctuations, and biological conditions—could not be fully reproduced.

Although the specimens in this study were prepared to simulate immature teeth, they do not fully replicate true immature teeth in terms of tissue composition and physical properties, as they were derived from mature teeth. Accordingly, the findings should be interpreted primarily as a comparison of material effects on structurally weakened dentin. Moreover, individual variations such as enamel, dentin, and cementum thickness, patient age, socioeconomic status, and parafunctional habits could not be reproduced in a laboratory setting, and absolute standardization of these factors was not achievable. Another limitation is the absence of periodontal ligament simulation, which plays an important role in force absorption and stress distribution. Therefore, caution should be exercised when extrapolating these results to clinical conditions.

Conclusions

Within the limitations of this *in vitro* study, the findings indicate that cavity design and restorative technique influence the fracture resistance of simulated immature teeth. The findings highlight the clinical importance of preserving remaining dentin structure, as restorative strategies that minimize additional removal of radicular dentin demonstrated more favorable outcomes. In particular, the use of SFRC either intraradicularly or intracoronally appears to be a promising alternative to fiber post–based techniques, as it reinforces structurally compromised teeth without the need for additional post-space preparation. These observations support the consideration of SFRC as a preferable restorative option for weakened immature teeth.

Acknowledgements

This study was funded by the Hatay Mustafa Kemal University Scientific Research Projects (Project No: 22.DHU.008).

Conflicts of Interest Statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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