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Fracture resistance of five intra-orifice barriers in endodontically treated mandibular premolars: an *in vitro* study

Otpornost na prelom pet različitih barijera koje se postavljaju na ulazu u kanal endodontski lečenih premolara u donjoj vilici: *in vitro* studija

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Abstract

Background/Aim. Endodontically treated teeth (ETT) are more prone to fractures than vital teeth, and insertion of an intra-orifice barrier (IOB) can increase their fracture resistance (FR). The aim of this study was to compare and evaluate the FR of ETT using smart dentin replacement (SDR), everX Flow (EXF), resin-modified glass-ionomer cements (RMGIC), calcium-enriched mixture (CEM), and universal flowable composite (UFC) as IOBs. **Methods.** After performing root canal treatment on 70 human mandibular premolars with a single root canal, the coronal 3 mm of root fillings were removed with heated instruments, except for the control specimens. Based on the IOB above the root canal obturation, the filled specimens were divided into six groups: RMGIC (n = 13), UFC (n = 13), SDR (n = 13), CEM (n = 13), EXF (n = 13), and a control group (CG; n = 5). A spherical steel insert with a diameter of 2 mm was used in the strength test with a universal testing machine. Data were analyzed using the Shapiro-Wilk test, analysis of variance, and least significant difference tests. The value of $p < 0.05$ is considered statistically significant. **Results.** The EXF group showed the highest mean FR of 759.9 ± 177.9 Newtons. The groups RMGIC, UFC, and EXF demonstrated a statistically significant difference compared to CG. CEM had a lower FR value than all groups except the SDR and CG. However, the FR of SDR was lower than that of the UFC and EXF groups. There were no significant differences between EXF, UFC, and RMGIC groups. **Conclusion.** Except for SDR and CEM, all other groups showed an increase in FR compared to CG. The results indicate that using EXF, UFC, or RMGIC as IOB can significantly enhance the FR of ETT compared to untreated controls. Clinically, selecting these IOBs may help prevent root fractures and improve the long-term prognosis of ETT.

Keywords:
bicuspid; dental cements; endodontics; in vitro; materials testing; root canal preparation.

Apstrakt

Uvod/Cilj. Endodontski lečeni zubi (*endodontically treated teeth* – ETT) skloniji su prelomima od vitalnih zuba, a umetanje barijera koje se postavljaju na ulazu u kanal (*intra-orifice barriers* – IOB) može povećati njihovu otpornost na prelom (*fracture resistance* – FR). Cilj rada bio je da se uporedi i proceni FR ETT korišćenjem „pametne“ zamene dentina (*smart dentin replacement* – SDR), *everX Flow* (EXF), smolom modifikovanog stakleno-jonomernog cementa (*resin-modified glass-ionomer cements* – RMGIC), kalcijum silikatnog cementa (*calcium-enriched mixture* – CEM) i univerzalnog tečnog kompozita (*universal flowable composite* – UFC) kao IOB. **Metode.** Nakon lečenja korena kanala 70 humanih jednokanalnih mandibularnih premolara, zagrejanim instrumentima su uklonjena koronarna 3 mm korenskih punjenja, osim kod kontrolnih uzoraka. Na osnovu IOB iznad opturacije korenskog kanala, uzorci pripremljeni za punjenje podeljeni su u šest grupa : RMGIC (n = 13), UFC (n = 13), SDR (n = 13), CEM (n = 13), EXF (n = 13) i kontrolna grupa (KG; n = 5). U testu čvrstoće univerzalnom mašinom za ispitivanje korišćen je sferični čelični umetak prečnika 2 mm. Za analizu podataka korišćeni su Shapiro-Wilk test, analiza varijanse i test najmanje značajne razlike. Vrednost $p < 0,05$ smatrana je statistički značajnom. **Rezultati.** Grupa EXF pokazala je najvišu srednju FR od 759,9 ± 177,9 Njutna. Grupe RMGIC, UFC i EXF pokazale su statistički značajnu razliku u odnosu na KG. CEM je imao nižu vrednost FR od svih grupa osim SDR i KG. Međutim, FR SDR bio je niži nego kod UFC i EXF grupa. Nije bilo značajnih razlika između grupa EXF, UFC i RMGIC. **Zaključak.** Osim SDR i CEM, sve ostale grupe pokazale su povećanje FR u poređenju sa KG. Rezultati ukazuju da korišćenje EXF, UFC ili RMGIC kao IOB može značajno poboljšati FR ETT u poređenju sa netretiranim kontrolama. Klinički, izbor ovih IOB može pomoći u sprečavanju preloma korena zuba i poboljšanju dugoročne prognoze ETT.

Ključne reči:
premolari; zub, cement; endodoncija; in vitro; materijali, testiranje; zub, korenski kanal, priprema.

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Introduction

Preservation of the remaining tooth structure is one of the main objectives of endodontic treatment [1]. Canal preparation with rotary instruments, which have a greater taper, heightens the risk of fracture in the coronal third of teeth. Consequently, it is essential to emphasize the reinforcement of these vulnerable regions [2]. After dental caries and periodontal disease, vertical root fractures (VRFs), described as fractures in teeth that run along the longitudinal axis of the root, are one of the common causes of tooth extraction [3]. Endodontically treated teeth (ETT) are more prone to fractures than vital teeth, which may vary from a typical cusp fracture to a catastrophic root fracture that requires extraction [4]. This can be prevented by strengthening the remaining radicular tooth structure, particularly in teeth exposed to high occlusal stresses. For this reinforcement, it is recommended to use restorative materials with compressive strength and modulus of elasticity similar to dentin, which helps reduce stress concentration at the dentin-restoration interface [5].

It is recommended to remove the 3 mm gutta-percha at the orifice of the root canal and replace it with a restorative material [6]. Insertion of an intra-orifice barrier (IOB) increases the strength of the ETT [7]. To replicate the stress-absorbing qualities of dentin, short fiber-reinforced composites have been developed to be utilized as a bulk basis for the restoration of high-stress teeth. The composite everX Flow (EXF) is recommended as an ideal IOB, especially in large cavities, as it allows better stress distribution [8]. One of the most popular materials for ETT restoration is smart dentin replacement (SDR) Plus Bulk Fill Flowable, a low-viscosity flowable composite that minimizes air bubble formation and enables it to reach deep places [9]. Another common option is resin-modified glass-ionomer cements (RMGICs), which chemically bond with dentin [10]. The RMGICs perform a similar acid-base reaction, but with the inclusion of resins. They allow for an effective setting and greater initial strength than glass-ionomer cements [11]. Calcium-enriched mixture (CEM), a water-based cement, is made up of calcium compounds. CEM is less toxic and more biocompatible, and is used for vital pulp treatment [12].

Despite the variety of materials available, limited data exist comparing their effects on fracture resistance (FR) when used as IOBs.

The aim of this study was to compare and evaluate the FR of ETT using SDR, EXF, RMGIC, CEM, and universal flowable composite (UFC) as IOBs. The null hypothesis was that the IOBs do not affect the FR of ETT and that there are no differences in FR offered by the five IOBs.

Methods

This *in vitro* study was conducted within four weeks, from January to February 2024, at the Department of Endodontics, Faculty of Dentistry, Gaziantep University, Gaziantep, Türkiye. This study was approved by the Ethics Committee of Gaziantep University (No. 2023/354, from November 01, 2023).

Sample size calculation

This sample size was computed using the mean and standard deviation (SD) values reported in two previous studies [13, 14]. Therefore, using G*Power 3.1 software (Universität Düsseldorf, Germany) and Cohen's *d* method with $\alpha = 0.05$, power of 95%, and computed effect size $f = 2.05$, a sample size of 13 was determined for each group. Five samples were chosen for the control group (CG). Thus, a total sample of 70 was determined.

Inclusion and exclusion criteria

Seventy human mandibular premolars with single root canals extracted for orthodontic procedures were chosen because they were of comparable size and had straight roots. The samples were first inspected under a stereomicroscope to ensure there were no cracks, and teeth with short and curved roots were eliminated. To rule out teeth with resorptive abnormalities and verify the existence of a single canal, intraoral periapical radiographs were also obtained. An ultrasonic scaler handpiece (Woodpecker HW-5L, Guangxi, China) with an ultrasonic scaler tip (G1) was subsequently utilized to clean all samples in order to remove calculus and debris. To avoid dehydration, the samples were then kept in distilled water for two weeks before use.

Specimen preparation

After measuring 14 mm from the root apex with a digital vernier caliper and marking it with a fine-point marker, the samples were decoronated along the marking using a low-speed handpiece with a diamond disc under water cooling. A size 10 K-type file (Dentsply Maillefer, Tulsa, USA) was inserted into the canal until it was observable through the apical foramen. The working length was determined 1 mm below this length.

Root canal preparation

Crown-down endodontic treatment of the specimens was carried out utilizing a nickel-titanium rotary instrument set (ProTaper Next, Dentsply Tulsa Dental, Tulsa, USA). A number 15 K-type file (Dentsply Maillefer, Tulsa, USA) was used to establish a glide path in the canals. In each sample, files X1 (#17.04), X2 (#25.06), and X3 (#30.04) were used in that order. During the preparation process, 2 mL of 5.25% sodium hypochlorite (NaOCl) (Wizard, Rehber Kimya San. ve Tic., Istanbul, Türkiye) was used for irrigation. After each file was replaced, 2 mL of 17% ethylenediaminetetraacetic acid (EDTA) was added. NaviTip sideport 31-gauge side perforated flushing needles (Ultradent, South Jordan, Utah, USA) were used for canal irrigation. After the root canals were prepared, the smear layer was removed by irrigating them with 3 mL of 5% NaOCl solution, followed by 3 mL of

15% EDTA for 1 min, and finally with 3 mL of 5% NaOCl solution. To ensure the effectiveness of the treatments, the root canals were lastly cleaned with 10 mL of distilled water and dried with sterile paper points (Aceonedent, Geonggi-Do, Korea).

The canals were subsequently filled with AH Plus Jet (Dentsply DeTrey, Konstanz, Germany) canal sealer and gutta-percha with 0.2% taper, according to the instructions of the manufacturer, using the lateral condensation technique. Then, the coronal 3 mm of root fillings was carefully removed using heated tools, with the exception of control specimens. By using a William's periodontal probe, this depth was verified. Microbrushes soaked with 70% ethanol were used to remove any remaining gutta-percha or sealer. Lastly, based on the IOB located above the root canal obturation, the filled specimens were split into the groups by manual allocation.

Placement of intra-orifice barriers

In the RMGIC group (n = 13), Equia Forte HT Fil (GC, Tokyo, Japan) was used. This is a high-viscosity glass ionomer restorative material consisting of fluoroaluminosilicate glass and an aqueous polyacrylic acid solution. The glass component contains SiO_2, Al_2O_3, CaF_2, AlF_3, and $AlPO_4$, which undergo an acid–base reaction to form a strong ionic bond with the tooth structure. The RMGIC capsule was mixed in the amalgamator for the duration specified by the manufacturer. Then, RMGIC was inserted into the prepared canal openings and polymerized for 20 s using a light-curing device (Elipar DeepCure, 3M ESPE).

In the UFC group (n = 13), G-ænial Universal Injectable (GC, Tokyo, Japan) was used. This is a highly filled, light-cured injectable composite containing urethane dimethacrylate, bisphenol A-ethoxylate dimethacrylate, and strontium glass fillers [69 weight percent (wt%)]. The root canal orifices were etched with 37% phosphoric acid for 20 s. The surface was then cleaned with water, and extra water was removed using an air syringe. The sample was then rinsed with water and dried with air. The bonding agent (Adper Single Bond 2, 3M ESPE, St. Paul, MN, USA) was applied to the area with a microbrush and polymerized with a light-curing device for 10 s. The pre-prepared canal orifices were filled with flowable composite in 1.5 mm increments, using a 470 nm visible light curing device placed 2 mm away for 20 s, in two passes.

In the SDR Plus group (n = 13), SDR Plus (Dentsply, Sirona, Germany) material was used, which contains modified urethane dimethacrylate resin matrix and filler (68 wt%). Root canal orifices were etched for 20 s using 37% phosphoric acid prior to restoration. After that, water was used to rinse the surface, and an air syringe was employed to remove any extra water. The enamel and dentin were then coated with Adper Single Bond 2, which was light polymerized for 10 s. Then, the SDR was installed and exposed to light polymerization for 20 s.

In the CEM group (n = 13), the material used was CEM (Bioniquedent Co., Tehran, Iran), and it contains calcium oxide, calcium phosphate, calcium carbonate, and calcium sulfate. The powder and liquid portions were added according to the manufacturer's instructions. The powder was progressively combined with the liquid for 15–30 s to wet all powder particles and achieve a dense consistency with a plastic spatula. Then, a ball-shaped mass of CEM cement was taken from the mixture and gently pushed into the canal orifices with a hand instrument. A wet cotton pellet was put on the IOB and allowed to set for 1 hr.

The material EXF (GC Dental, Tokyo, Japan), used in the EXF group (n = 13), contains E-glass fibers (1–2 mm), bisphenol A-glycidyl methacrylate, triethylene glycol dimethacrylate, and barium glass filler. Before restoration, the surfaces were etched with 37% phosphoric acid, rinsed with water, and dried using an air syringe. The bonding agent (Single Bond 2) was coated and lightly polymerized for 10 s. Finally, EXF was applied and lightly polymerized for 20 s.

In the CG (n = 5), there was no gutta-percha removal or IOB application.

For full setting, the specimens were then kept for 48 hrs at 37 °C and 100% humidity. The roots' apical 5 mm were submerged in molten wax. This resulted in a periodontal ligament gap of around 0.2–0.3 mm. Then, all specimens were placed in plastic cylinder molds that were 20 mm in diameter and 20 mm in height and embedded in acrylic resin (Imicryl, Konya, Türkiye).

Fracture testing

To prevent bias, all of the aforementioned steps were completed by a single operator (IY). The operator was not blinded to the group allocation. This represents a potential source of operator bias and is acknowledged as a limitation of the study. A spherical steel insert with a diameter of 2 mm (perpendicular to the tooth's long axis) and a constant crosshead speed of 1 mm/min was used in the strength test, which was carried out using a universal testing machine (AGS-X, Shimadzu Corporation, Tokyo, Japan). Until the root broke, the loading segment with the tip was positioned in the middle of each specimen's groove opening. The moment at which a sharp decline of more than 25% of the force utilized became evident was considered a fracture [15]. Newtons (N) were used to record the force at fracture.

Statistical analysis

The numerical variables' conformance to the normal distribution was verified using the Shapiro-Wilk test. The analysis of variance (ANOVA) and least significant difference tests were used for analyzing normally distributed data across six groups. For the recorded forces, we derived the mean and SD. The analyses were carried out using SPSS 22.0 Windows package application (SPSS Inc., Chicago, IL, USA). The value of $p < 0.05$ was accepted as significant.

Results

There was a significant relationship between groups (Table 1 and Figure 1).

The highest mean fracture strength value (759.9 ± 177.9) among the tested groups was observed in the teeth with EXF, followed by UFC (741.2 ± 163.4). The lowest average FR value (519.6 ± 60.2) was observed in CG, and the closest value to CG (539.2 ± 107.6) was in the CEM group.

In comparing normally distributed variables across six groups, ANOVA and least significant difference tests revealed a significant difference between the FR values obtained from the groups (p = 0.001). When the FR of the groups was evaluated using the pairwise comparison test, all groups except SDR and CEM showed a statistically significant difference compared to CG. The UFC group showed significantly higher FR than all groups except EXF and RMGIC, while the CEM group showed a lower FR value than all groups except SDR and CG. The EXF group showed significantly higher FR against all groups except the UFC and RMGIC groups. However, SDR showed lower FR against UFC and EXF groups. There was no significant difference between EXF, UFC, and RMGIC.

Table 1

Fracture resistance of experimental groups and statistical comparisons

Group	Mean ± SD	Median (Min–Max)	Homogeneous subset*
EXF (n = 13)	759.9 ± 177.9	709 (527–1,098)	c
UFC (n = 13)	741.2 ± 163.4	772 (516–1,036)	c
RMGIC (n = 13)	659.8 ± 107.5	699 (461–856)	bc
SDR (n = 13)	617.5 ± 87.8	596 (501–839)	ab
CEM (n = 13)	539.2 ± 107.6	558 (399–695)	a
CG (n = 5)	519.6 ± 60.2	520 (435–605)	a

SD – standard deviation; EXF – everX Flow; UFC – universal flowable composite; RMGIC – resin-modified glass-ionomer cements; SDR – smart dentin replacement; CEM – calcium-enriched mixture; CG – control group; n – number; Min – minimum; Max – maximum.

***Note*. *Lowercase letters indicate statistical groups; groups sharing the same letter are not significantly different, while statistically significant differences (*p* < 0.05, analysis of variance and least significant difference test) occur between all groups with different letters, including comparisons involving multiple groups simultaneously.**

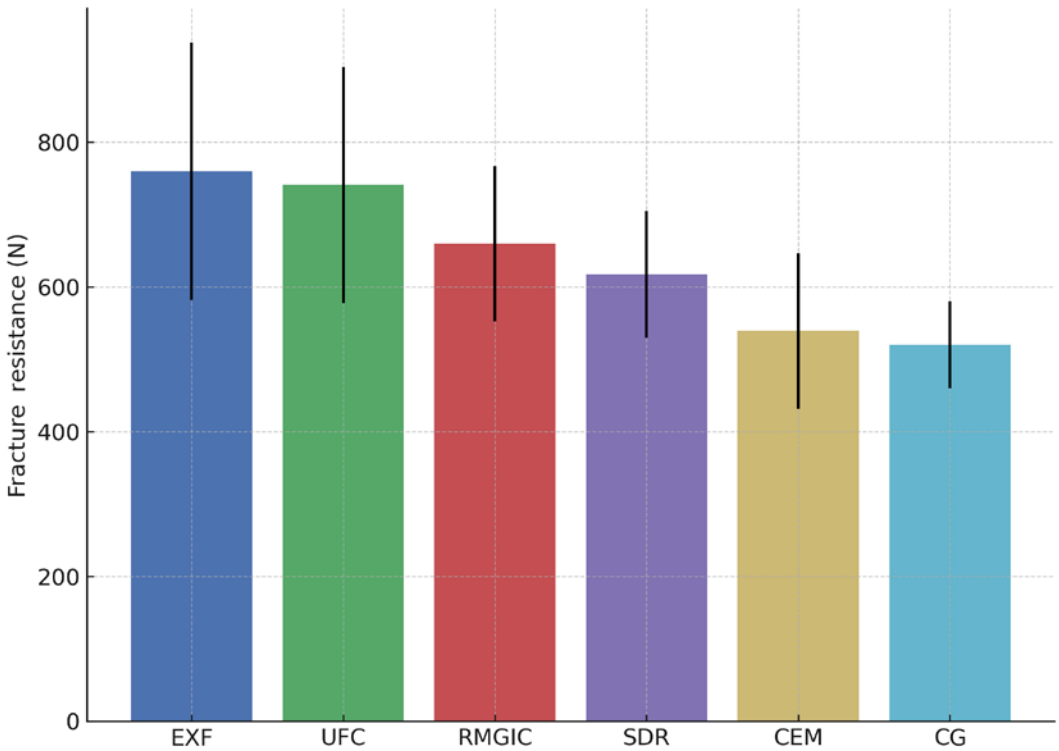

Fig. 1 – Fracture resistance results.
For other abbreviations, see Table 1.

***Note*. The bar graph illustrates the mean fracture resistance for each experimental group, with standard deviations indicated as error bars.**

Discussion

Due to extensive dentin removal, particularly in the cervical area, the larger preparation that results from the use of rotary instruments can lead to VRF [3]. Furthermore, dehydration and irrigant exposure weaken dentin and make it more susceptible to VRF [16]. Additionally, while evaluating the VRF risk of ETT, additional characteristics, including the size and curvature of the external root, as well as the form and morphology of the root canal, should be taken into account [17]. Strengthening the radicular part and the coronal structure should be the main priority. IOB has been suggested to lower the risk of fracture and support ETT [13].

Using five distinct IOBs, our study estimated the FR of mandibular premolars that had undergone endodontic treatment. Fracture strength data of the test groups showed that the type of IOB used had a substantial impact on the roots' FR. According to the results, CG had the lowest FR, whereas EXF and UFC had the greatest FR. The lowest FR levels were observed in CG, which was consistent with previous research [5, 14, 18]. Our findings also showed significant differences in FR between these groups. IOB placement of EXF, UFC, and RMGIC significantly increased the FR of ETT. Therefore, the null hypothesis of the present study, that there would be no significant difference between the tested groups, was rejected. The higher FR values observed in our research may be mostly attributable to the tested IOBs' strong adhesive qualities to dentin. This explains why RMGIC had a strong FR relative to CG and CEM, but less than the UFC, and no discernible difference in FR compared to the UFC and EXF groups in the current study. Additionally, the EXF group showed greater FR, in line with other studies [19, 20]. The EXF group has been shown to be useful in strengthening ETT as IOB [21]. The presence of short fibers integrated into the matrix, which greatly enhanced the material's resistance to crack propagation and reduced the stress intensity at the crack tip and its unstable propagation, may have contributed to the increased FR of EXF [19]. However, this contrasts with the findings of Gupta et al. [18], which indicated that the FR of RMGIC was greater than that of fiber-reinforced composite. This discrepancy might be attributed to the fact that in the study mentioned earlier, the fiber was employed as a separate layer (Ribbond, Seattle, Washington, USA) on the cavity floor alongside the composite filling.

Previous research has demonstrated that UFCs are more successful than RMGIC at improving FR as an IOB, as was the case in our study [5, 13, 14]. RMGIC has an elastic modulus similar to that of dentin and a strong flexural strength. As a result, the material may bear the stress before the load is transferred to the root. Additionally, the dentin-RMGIC contact is more resistant due to its chemical connection to the dentin surface [18]. Compared to traditional composites, UFCs have been reported to provide increased flowability, better adaptability to the interior cavity wall, and more elasticity [22]. However, UFC's lower stiffness and greater polymerization shrinkage are significant disadvantages compared to composite resins [23]. This may help explain why the FR of RMGIC in the current study was not significantly different from that of UFC, showing a good FR relative to CG but still lower than UFC.

UFC showed more FR than CEM in the present research. This could be because the resin's low viscosity made it easier for UFC to adhere to the intra-orifice dentin. Compared to mineral trioxide aggregate (MTA), CEM has a smaller film thickness, a higher flow rate, and a faster setting time [24]. Although CEM increased the FR of immature anterior teeth at 6 months [25], there were no significant differences between the tested groups in our study, except the CEM group. The elastic modulus of CEM is comparable to that of dentin. However, the impact of FR as IOB is minimal. MTA, which has mechanical properties consistent with CEM, provided the lowest FR in multiple studies comparing the FR of RMGIC, fiber-reinforced composite, and MTA as IOB [14, 26]. Regardless of the type of adhesive employed, the study by Savadi Oskoee et al. [27] revealed that RMGIC's shear bond strength was much higher than CEM's. Since the adhesive system allows them to penetrate and interlock into surface pores and imperfections, the bonding process of CEM is most likely micromechanical. Additionally, the combination of powder and liquid alters the mechanical characteristics of the CEM, which in turn influences the FR values [28]. Furthermore, as shown below, rather than having a favorable modulus of elasticity, CEM's inability to strengthen roots is most likely due to its weakening under stresses and its absence of bonding to dentin.

Although tooth strength is determined by the amount of tooth structure remaining, the FR could be increased by inserting a further 3 mm barrier into the root canal. Stress transmission along the length of the tooth depends on the pericervical dentin, which is situated close to the alveolar crest and extends around 4 mm coronally and apically from the crestal bone. The tooth may be prone to fracture if this pericervical dentin is lost [5]. Gao et al. [29] highlighted this point by stating that the cervical portion of the root experiences the greatest stress due to occlusal pressures in ETT, and that this stress increases as the instrument's taper becomes larger. To restore the missing pericervical dentin in the experimental groups, 3 mm of barrier material was used in place of gutta-percha. This enhanced FR when the restorative materials flexed under occlusal loading, dispersing the stresses equally over the dentin-restoration contact [5, 14]. Up to 4 mm of SDR can be polymerized at once, which is 1 mm deeper than the depth required by the IOB. Additionally, it has a modified methacrylate resin that lowers the pressures generated by shrinkage *via* slowing down the rate of polymerization [30].

According to Atalay et al. [31], ETT restored with fiber-reinforced composite (everX posterior) or bulk-fill/fluid bulk-fill, like SDR in our study, does not have a different FR than those restored with conventional nanohybrid resin composite similar to UFC. Similarly, no significant difference was found between UFC and EXF in our study. The results of our research were corroborated by Ozsevik et al. [20], who found that teeth with root canal therapy and those reconstructed with fiber-reinforced composite material (everX posterior, GC, Tokyo, Japan) had fracture strength values that were quite similar to those of the intact tooth group. Even though their findings were comparable to those of our study, the aforementioned study differs in certain ways from the current investigation. First, rather than evaluating IOBs, their goal was to assess the FR of composite fillings. Additionally, they tested fillings in molars rather than uncrowned, single-rooted premolars, and they used everX posterior instead of EXF as the short fiber-reinforced flowable resin.

Within the limitations of this *in vitro* study, EXF and UFC demonstrated the highest FR and may therefore be recommended as IOB materials for ETT under high occlusal stress. EXF, containing short fibers that mimic dentin's elasticity, provides effective stress distribution and is particularly suitable for posterior teeth with wide canal openings. On the other hand, UFC offers easier handling, excellent adaptation, and lower cost, making it a practical choice for routine cases. Although RMGIC showed slightly lower resistance, its chemical adhesion and fluoride release can be advantageous in cases requiring enhanced sealing. CEM and SDR, with lower reinforcement potential, may not be ideal in teeth subject to high masticatory forces. Further long-term clinical studies are needed to evaluate the performance of these materials under cyclic loading and thermomechanical stress.

This *in vitro* study inherently has several limitations. Firstly, there was a possibility of sampling and representation bias because the study included only healthy mandibular premolars. Secondly, despite extensive efforts to standardize the form and size of the premolars, undetectable canal defects may still have been present and could have influenced the force readings. Thirdly, in the current investigation, the force was applied in a single direction and at a single spot to evaluate FR, which does not accurately replicate intraoral environments. A fourth limitation is that the operator was not blinded to group allocation, creating the potential for operator bias. As a fifth limitation, this study applied a single, static vertical load to the fracture, which does not fully reflect the complex occlusal stresses occurring within the mouth. Cyclic loading and thermomechanical aging could have provided a more accurate simulation of clinical conditions. Therefore, the results should be interpreted with caution, and further *in vitro* studies that include dynamic and thermal fatigue are recommended. Lastly, the inability to apply the study's findings in clinical settings is another shortcoming. In addition, it is necessary to explore the possibilities of using a potential IOB candidate for further studies. Future research should include cyclic loading and other demanding simulations to replicate clinical conditions better.

Conclusion

Among the tested intra-orifice barrier materials, everX Flow exhibited the highest fracture resistance, while universal flowable composite and resin-modified glass-ionomer cements showed comparable performance. Except for smart dentin replacement and calcium-enriched mixture, all materials significantly increased fracture resistance compared with the control group. These results indicate that everX Flow, universal flowable composite, and resin-modified glass-ionomer cements may provide superior reinforcement in endodontically treated teeth, making them preferable choices in clinical practice. Further *in vitro* and clinical studies are needed to confirm their long-term performance under functional conditions.

Conflict of interest

The authors declare no conflict of interest.

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