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ORIGINAL RESEARCH

Resistance to fracture of simulated external cervical resorption cavities repaired with different materials

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Abstract

The aim of the study was to evaluate the fracture resistance (FR) of teeth with simulated external cervical resorption (ECR) cavities repaired with different materials. Following the shaping of the 80 human permanent maxillary central incisors, standard ECR cavities were prepared and restored with a nanohybrid composite resin; a high viscosity GIC Equia Forte Fill; Biodentine; Biodentine + nanohybrid composite resin; MTA BIOREP; MTA BIOREP + nanohybrid composite resin. Then, the root canals were obturated with AH Plus and gutta-percha. The roots were embedded acrylic resin blocks and fracture strength test was applied. The highest FR was observed in the Biodentine group, while the lowest was in Equia group ($p < 0.05$). No significant results were observed among composite, Biodentine + composite, MTA BIOREP + composite and MTA BIOREP ($p > 0.05$). Biodentine may be a preferable material for repairing ECR cavities. Adding a composite layer on MTA BIOREP and Biodentine did not improve the FR of these materials.

KEYWORDS

calcium silicate, external cervical resorption, fracture resistance

INTRODUCTION

External cervical resorption (ECR) is a very aggressive type of inflammatory resorption located in the cervical area of the tooth and may cause huge tissue loss [1]. It generally involves dental, periodontal and/or even pulpal tissues [2, 3].

These cases are commonly asymptomatic and not easy to detect. It has no classic radiographic sign [4]. It may show itself as a 'pink spot' or may be diagnosed with periodontal probes [5]. If the lesion invades the pulp tissue, the patient may suffer from apical periodontitis or (ir)reversible pulpitis [4]. A careful clinical and radiographic examination will assist in the differential diagnosis of conditions such as buccal caries and internal root resorption [4].

As for the aetiology, Mavridou et al. reported that ECR usually occurs due to multifactorial causes and is not idiopathic [6]. There are several predisposing factors for ECR such as orthodontic treatment, internal bleaching, traumatic injury, periodontal therapy, some restorative treatments, malocclusion, extraction of the neighbour tooth, herpes zoster and the use of bisphosphonates [4, 5, 7–9]. When taking into consideration of these predisposing factors and challenging diagnosis process, it is not easy to handle these cases. The treatment options which are dental treatment, surgical intervention, intentional replantation, periodic review or extraction depend on several factors such as the ECR size, circumferential spread, proximity to the root canal, accessibility and restorability of the cavitation area [4, 10, 11]. Patel et al. created a new three-dimensional classification of ECR [10] by using cone-beam computed tomography (CBCT) and clarified the treatment of ECR in the light of this classification [11].

The use of calcium silicate-based materials has been suggested for the treatment of ECR restorations due to

their biocompatibility, antibacterial properties, good aesthetic results and excellent sealing properties [4]. Some researchers recommended using Biodentine (BiodentineTM Septodont) with glass ionomer and/or composite resin restoration in ECR cases where aesthetic expectations are high [12, 13]. MTA BIOREP (Itena) is a high plasticity endodontic bioceramic restorative cement. It is marketed in capsule and liquid form similar to Biodentine. According to the manufacturer, it has superior features such as fast setting time, easy manipulation, excellent marginal sealing ability and lower solubility when compared to the other similar products on the market [14]. These properties of the product should be studied.

Although there are several articles in the literature about ECR, most of them are case reports, reviews or case series. Patel et al. examined ECR in details in a series of articles he published and described its aetiology, histopathology, treatment and its follow-up one by one [4, 5, 10, 11]. Despite these guide articles, the number of original research articles on ECR therapy is still low today. In cases where the ECR perforates the pulp, the tooth weakens due to the loss of tooth tissue following both endodontic treatment and repair of resorptive lesion. However, there is no study in the literature assessed the fracture resistance (FR) of teeth with simulated ECR cavities. This study aimed to evaluate the FR of teeth with simulated ECR cavities perforating pulp tissue repaired with different materials. The null hypotheses were as follows: (1) There would be no difference between the materials used in the restoration of ECR cavities regarding the FR of the tooth, and (2) the use of calcium silicate-based materials with a composite layer in ECR cavities does not affect the FR of the tooth compared with its single-use.

METHODS AND MATERIALS

Sample selection

The study protocol was approved by the Local Ethics Committee (E-54022451-050.05.04-23 223). The power analysis was performed with G*Power 3.1 software (Heinrich Heine University) using data from a similar study [15]. The sample size was calculated as a minimum of 10 for each group (alpha probability of error = 0.05, power = 0.95) for this experimental study.

The experiment design is summarised in Figure 1. Eighty human permanent maxillary central incisors were selected. Root canal morphology was checked with initial periapical radiographs. Caries, crack, fracture and any root resorption were inspected under a surgical microscope (Leica M320, Leica microsystems). Teeth with immature apex, calcified canals, endodontic treatment and old fillings were not used. The teeth which have straight root and root length of 15 ± 1 mm were included in the study. The mesiodistal and buccopalatal diameters of the teeth were measured using a digital calliper at the cementoenamel junction (CEJ). Roots presenting a difference of %20 from the mean were discarded from the study [16]. Ten of these teeth that meet the inclusion criteria were used as a negative control group.

Root canal preparation

The patency of the root canals was checked with a size #10 K file following the preparation of access cavity. The working length was calculated by withdrawing 1 mm from the point where the root canal instrument exited from the apical terminus. The root canals were shaped with Protaper Next system (Dentsply Sirona Endodontics) up to X3 (30/0.07). Total amount of 15 ml 2.5% sodium hypochlorite (NaOCl) was used during the shaping procedures. Root canals were dried with the paper points following the final irrigation.

Pilot study

In the present study, it was aimed to create ECR cavities according to the Patel classification system as a 2Bp class (Table 1) [11]. To understand the required depth of these cavities, a pilot study was conducted with 30 other teeth meeting the inclusion criteria of the present study. The teeth in the pilot study were selected according to all the criteria described so far and underwent all the pre-treatments mentioned above. These teeth were decoronated from the cementoenamel junction, the least distance between the buccal borders of root wall and root canal was measured, and the mean values of these data were calculated. In the light of these results, the depth of the ECR cavity was decided to be 3 mm to create cavities with pulpal involvement. The teeth in the pilot study were discarded and not used in this experimental study.

Preparation of ECR cavities

Following the determination of the depth of ECR cavities by the pilot study, the ECR cavities of the experimental teeth were prepared 2 mm below the CEJ. The ECR cavities were prepared on the coronal third and the buccal surface of the root. The ECR cavity was 3 mm (depth) × 2 mm (height) × 3 mm (width) that lay from the mesial to distal sides (Figure 1a). Ten of these teeth were selected as a positive control group.

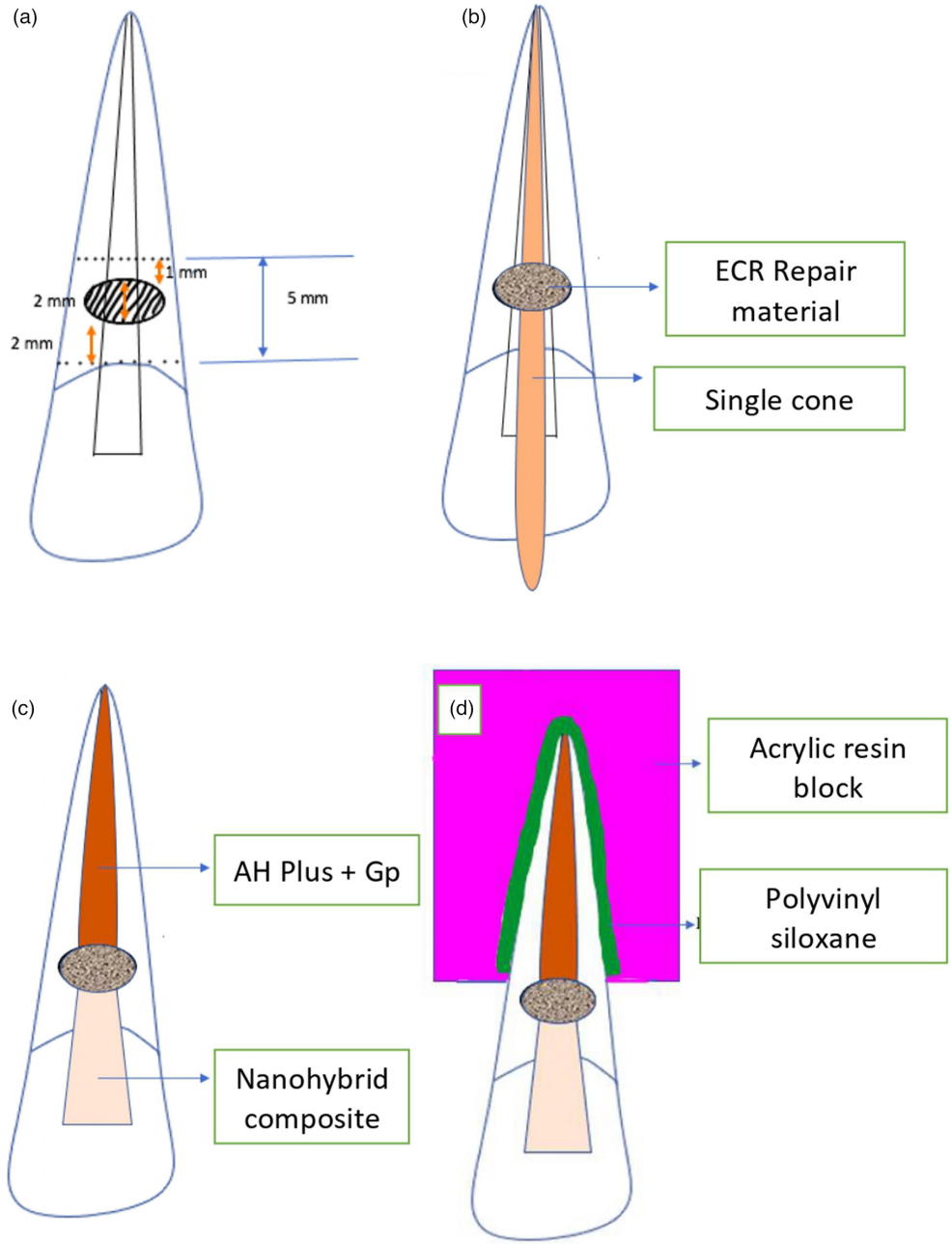

FIGURE 1 Schematic presentation of prepared ECR cavity (a); obturated root canal and repaired ECR cavity (b); the access cavities permanently restored with NHC (c); the tooth inserted into the acrylic resin block (d).

Distribution of the groups

Before the ECR repair, a single cone (Protaper X3 gutta-percha) was placed into the root canal of these 60 specimens to maintain patency (Figure 1b). Then ECR cavities were repaired externally as follows:

- Equia group (n = 10): The resorption area was restored with a high viscosity GIC Equia Forte Fill (GC Corp.,).
- Composite group (n = 10): The resorption area was restored with a nanohybrid composite resin Z350 XT (NHC) (3 M ESPE) incrementally.
- Biodentine group (n = 10): The resorption area was restored with Biodentine. Five drops of liquid were poured into the powder capsule and shook for 30 s on a mixing device.
- Biodentine + Composite group (n = 10): The resorption area was restored with Biodentine which was prepared as described above. After 12 min. of setting time, 2 mm

TABLE 1 Details of Patel classification class 2Bp.

Patel classification; 2Bp.
Height: 2: Extends into the coronal third of the root and apical to the bone crest (subcrestal).
Circumferential spread: B: >90° to ≤180°.
Proximity to root canal: p: Pulpal involvement.
Treatment protocol:
External repair with endodontic treatment

of the superficial Biodentine was removed and the remaining cavity was restored with NHC.

- MTA BIOREP group ($n = 10$): The resorption area was restored with MTA BIOREP. Four drops of liquid were poured into the powder cap and shook for 30 s on a mixing device.
- MTA BIOREP + Composite group ($n = 10$): The resorption area was restored with MTA BIOREP. After 15 min. of setting time, 2 mm of the superficial MTA BIOREP was removed, and the remaining cavity was restored with NHC.

After the completion of ECR cavity repair, all specimens were obturated with AH Plus (Dentsply DeTrey Gmbh) and gutta-percha using the cold lateral condensation technique. The quality of the root canal obturations was checked with periapical radiography. The access cavities of all the samples (Black I) were restored permanently with a NHC incrementally (Figure 1c, Figure 2).

All composite applications were implemented in the same way throughout the present study. During the adhesive treatment, the cavities were acid-etched with 35% phosphoric acid (Ultradent Products) for dentin 15 s, and enamel 30 s and rinsed with water. After drying the cavity gently, a universal adhesive system (Single Bond Universal, 3 M ESPE) was applied and polymerised for 10 s using an LED light-curing unit (3 M Elipar™DeepCure-S, 3 M ESPE). Then, composite restorations were performed incrementally and polymerised for 20 s. All the samples were stored in 100% humidity at 37°C for 2 weeks until the FR test occurred.

Fracture resistance test

The protocol was modified from Aktemur Türker et al.'s study [15]. Starting from 1 mm below the ECR cavity, the entire root surface of all specimens was covered with wax (0.2 mm thick). Then, the root surface covered with wax was embedded in self-cure acrylic resin blocks (Meliodent, Bayer Dental), leaving coronal third of the root (approximately 5 mm) exposed.

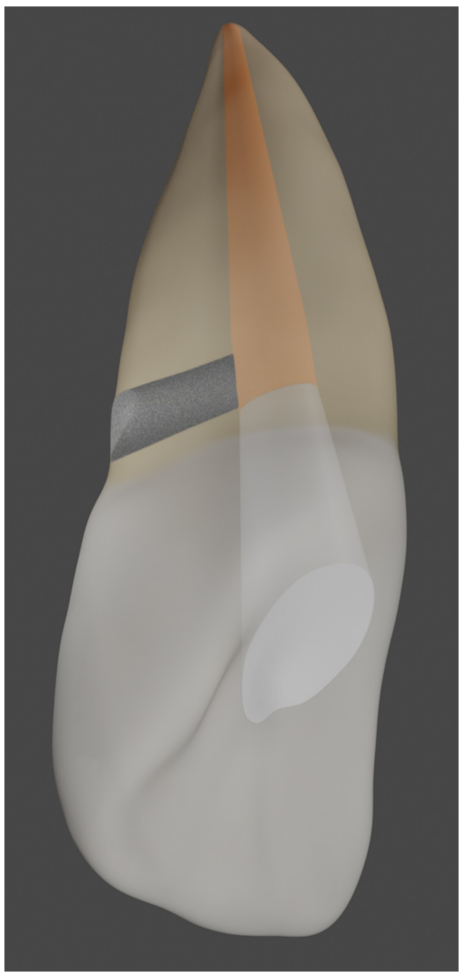

FIGURE 2 3D modelling of the final form of the restored samples (the orange colour represents root canal obturation, grey colour represents restored ECR cavity, white colour represents composite restoration).

Before the acrylic resin completed its polymerisation, the tooth was removed from its socket and the wax on the root surface was cleaned. This cleaned surface was covered with polyvinyl siloxane impression material. By this way, the periodontal membrane was imitated. The roots covered with this impression material reinserted into the acrylic resin block (Figure 1d). These blocks were positioned in a Universal Testing Machine (Instron Corp.,) at a 135° angle to the long axis of the roots at a crosshead speed of 5 mm min^{-1} until failure occurred (Figure 3). The force when the fracture occurred was recorded in Newtons. The mode of failure was also analysed by using the following scale: I—coronal fracture, II—fracture at the limit of embedding resin, III—fracture partially extending into the embedding resin, IV—fracture confined within the embedding resin (Table 2) [17]. One specimen from each group was selected and examined by scanning electron microscope (SEM) with different magnifications. The

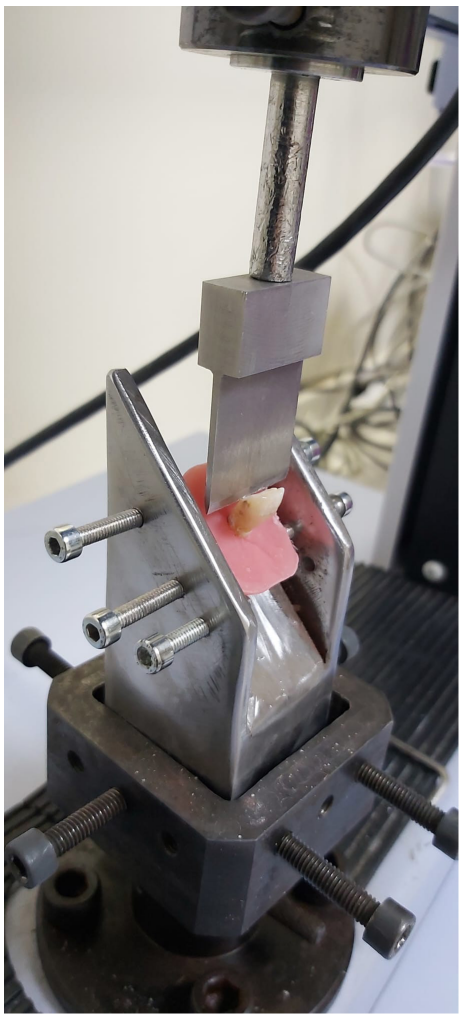

FIGURE 3 Experimental set-up for the fracture resistance test on the universal testing machine.

specimens were dehydrated and then gold-sputtered for SEM examination.

Statistical analysis

IBM SPSS V23 (SPSS Inc.,) was used for the analyse of the data. Shapiro–Wilk test was used to evaluate the normal distribution, one-way analysis of variance (Welch) was used to compare FR values according to groups, and Tamhane's T2 test was used for multiple comparisons. The significance level was taken as $p < 0.05$.

RESULTS

The mean and standard deviation of FR values of tested groups are shown in Table 3. Among the tested groups, the highest FR was observed in the Biodentine group, while the lowest was in Equia group ($p < 0.05$). Adding a composite layer on calcium silicate-based materials did not make any positive effect on the FR of the materials ($p > 0.05$). Additionally, no significant results were observed among composite, Biodentine + composite, MTA BIOREP + composite and MTA BIOREP ($p > 0.05$). As expected, the positive control group showed statistically lower FR and negative control group showed statistically higher FR results than all groups ($p < 0.05$).

TABLE 2 Distribution of the teeth within the groups according to the fracture pattern. All tested groups showed widely non-restorable fractures and no Type I fracture was observed.

	Type II	Type III	Type IV
Equia	-	9	1
Composite	-	9	1
Biodentine	3	7	-
Biodentine + Composite	1	8	1
MTA Biorep	3	7	-
MTA Biorep + Composite	2	8	-

Regarding failure mode, no Type I fracture was observed in the present study. All tested groups showed widely non-restorable fractures (Table 3). Type II (Figure 4a) fractures were observed in a few samples in calcium silicate-based materials with or without composite restorations. However, the common fracture mode was Type III (Figure 4b) or Type IV (Figure 4c). In the obtained SEM images, many micro and macro crack lines were observed on the entire root surface in ECR cavities repaired with Equia (Figure 4c), while slightly deep and few micro crack lines were observed in the calcium silicate-based materials + composite groups (Figure 4a, Figure 4f). In the composite group, not only crack lines but also ruptures on the repair material surface were detected (Figure 4d). On the MTA BIOREP group, a deep and wide crack line was observed at the MTA BIOREP-root surface contact line (Figure 4e).

DISCUSSION

Diagnosis and treatment of ECR is still an unclear issue for clinicians. Although there are some review articles about the histopathology, distribution, classification and treatment options of these kinds of cases, in vivo and in vitro studies on this subject are very few in the literature. In this study, ECR cavities extending the pulp space were created in in vitro conditions and following the restoration with several dental materials including calcium silicate based materials, FR of these teeth was evaluated. Biodentine showed higher resistance against fracture than the tested groups and adding a composite layer on calcium

TABLE 3 Median, mean and standard deviation of FR values (Newton) of tested groups.

	Mean ± SD	Median (minimum-maximum.)	Test statistics	*p*-value
Equia	410.5 ± 83.7^{e}	387.2 (323.1–566.4)	F = 114.092	<0.001
Composite	547.4 ± 126.3^{ce}	535.1 (415.0–795.4)		
Biodentine	806.3 ± 98.4^{d}	751.1 (701.7–996.8)		
Biodentine + Composite	557.6 ± 82.0^{c}	543.1 (419.5–691.6)		
MTA Biorep	563.7 ± 67.4^{c}	580.4 (462.9–666.2)		
MTA Biorep + Composite	496.8 ± 60.1^{ce}	502.5 (431.7–619.4)		
Positive control	215.6 ± 49.6^{b}	205.6 (122.0–295.5)		
Negative control	1244.0 ± 125.9^{a}	1298.1 (1011.0–1357.3)		

Note: F: One-way analysis of variance (Welch) Values for the groups marked with different superscript letters were significantly different ($p < 0.05$).

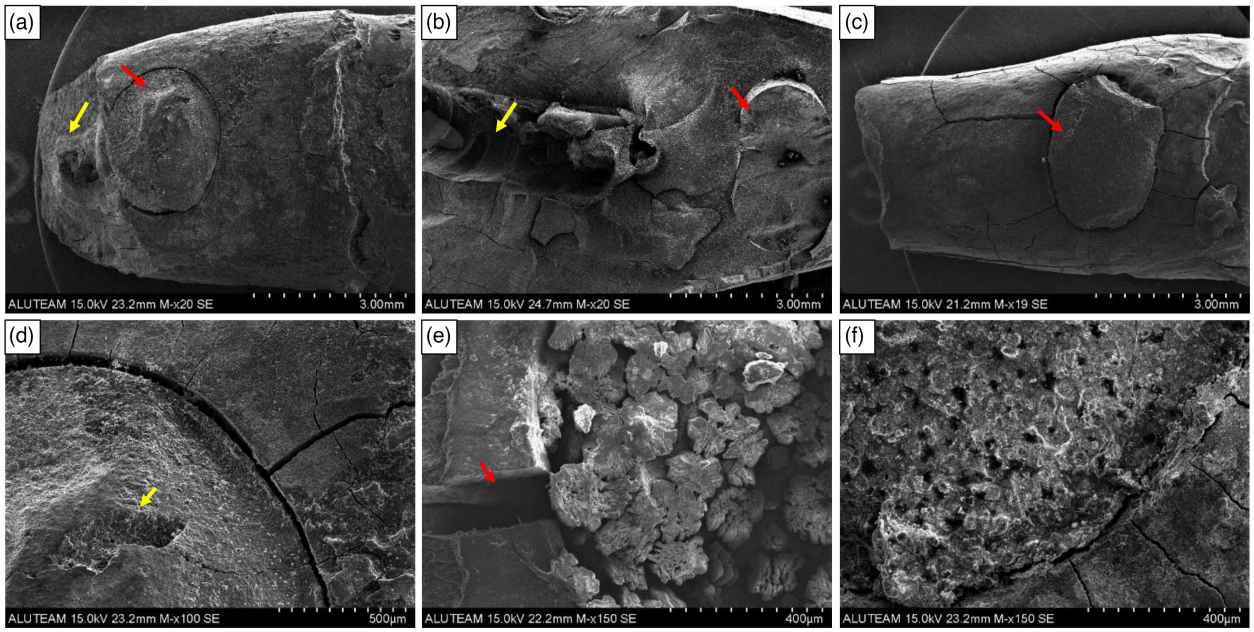

FIGURE 4 Representative SEM images of the ECR cavities. An example of Type II, Type III and Type IV fractures are shown in Figure 3a, Figure 3b and Figure 3c, respectively. In these images, while yellow arrows show the damaged gutta-percha, red arrows show Biodentine + composite, Biodentine and Equia in ECR cavities, respectively. Crack types are shown in Figure 3d, Figure 3e and Figure 3f; (d) rupture (yellow arrow) on the composite surface; (e) a macro crack (red arrow) in the MTA Biorep group; (f) shallow microcracks on root surface in MTA Biorep + composite group.

silicate-based cements did not improve their FR. In the light of these results, the first and second hypothesis were rejected.

Although there is not enough study about ECR and its treatment protocols, there are many studies about internal root resorption (IRR) and its management in the literature. The materials used in these studies may also light the way for ECR researches. Khalil et al. used GIC and calcium silicate cement in the treatment of IRR cavities and reported that GIC was not good enough to reinforce the teeth against fracture due to its long setting time and sensitivity to hydration [18]. The results of the present study are also consistent with these outcomes. Aslan et al. restored IRR cavities with gutta-percha and/or MTA, and then evaluated the stress distribution. In the MTA-filled resorption models, the stresses were distributed more homogenously than in the gutta-percha-filled models. The researchers attributed this to the fact that MTA behaves like dentin due to its elastic modulus similar to dentin and shares the incoming stress with dentin [19]. In another study, the stress distribution in mandibular molar teeth with different iatrogenic root perforations repaired with Biodentine or MTA were evaluated. The authors reported that although these two materials had very similar modulus of elasticity with dentin, the stress value were higher in MTA group. The

most likely explanation for this may be that the elastic modulus of Biodentin is closer to dentin than that of MTA [20]. In the present study, Biodentine also showed higher FR than the MTA group.

MTA and Biodentine are the popular calcium silicate-based materials that are used in challenging cases. Application procedures of these materials require great attention and care. Adhesion of calcium silicate-based materials to the root dentine will increase the material's reinforcing effect [21]. Hashem et al. recommended waiting at least 2 weeks before performing overlying composite restoration on Biodentine to achieve adequate bond strength [22]. However, it should be kept in mind that a flap operation is indicated in 2BP class ECR cavities in which the clinician cannot wait for hours and must finalise the treatment in one visit. In the present study, composite restoration was applied over calcium silicate-based materials just after waiting the setting time of the materials recommended by their manufacturers. And according to the results, Biodentine (without composite layer) had the highest FR values. In the 2-week period until the FR test, the Biodentine group may fully mature and affect this group's results positively. Although the same condition is true for the MTA BIOREP group, the smaller particle size of Biodentine compared with MTA BIOREP may have resulted in better micromechanical adhesion of Biodentine to dentin and thus better resistance to fracture [23, 24]. But adding a composite layer on MTA BIOREP and Biodentine did not create any positive effect on the FR of the teeth. The possible reason for these results may be the low pH caused by orthophosphoric acid, which may affect the chemical bonding process by disrupting the hydration of these calcium silicate-based materials [25] and the short waiting time for the material to set.

The biggest challenge in in vitro studies is mimicking clinical conditions. Thermomechanical ageing (TA) is one of the most effective methods to ensure the similarity of samples to clinical conditions in in vitro studies. However, there are a few studies about the importance of TA on FR [26, 27]. Marci et al. showed that TA did not affect the FR of several post-core systems, except composite resin cores which demonstrated no resistance to mechanical ageing [26]. de Kujiper et al. showed that cold and hot applications in ageing processes such as thermal cycling may cause a change in the material that will represent the periodontal ligament, this change may affect the results and prevent real results from being obtained [27]. In the present study, TA was not applied to the samples (1) in order not to add another unknown variable to the study; (2) to protect the properties of the material simulating periodontal membrane [15, 26].

There is a dilemma in the literature regarding which adhesive technique to use for the highest bond strength between bioactive materials and composite. Kayahan et al. evaluated the effect of the etching procedure on the compressive strength of several calcium silicate-based materials and reported that Biodentine had the highest compressive strength ($p < 0.0001$) among all tested cements, including MTA [28]. Krawczyk-Stuss et al. showed that prolonged etching time increased the bond strength of Biodentine to composite restoration [25]. In the recent study, Biodentine had better FR values when used without composite. On the other hand, no significant result was obtained between MTA BIOREP + composite and Biodentine + composite groups. The used adhesive technique and etching time may affect the FR of the tested materials. In addition, Biodentine had better results than MTA BIOREP when used without composite. Low water/cement ratio of Biodentine could be the main reason for its higher compressive strength [29]. Another possible reason for this could be the larger amount of calcium released by Biodentine which may lead to better interfacial layer and tag-like structures [30].

The treatment of an ECR invading pulp tissue generally needs a surgical approach. For this purpose, the ECR will be excavated externally by raising a mucoperiosteal flap. Use of 90% aqueous solution of trichloroacetic acid (TCA) which induce coagulation necrosis on the resorption defect has been recommended [31]. On one hand, it inactivates clastic cells and may penetrate small resorptive defects [32, 33]. On the contrary, it has carcinogenic and genotoxic effects [34, 35]. To the best of the authors' knowledge, there is no study that compare the treatments with or without TCA on the success of ECR management. Uysal and Güngör assessed the effect of TCA on the bond strength of MTA and Biodentine [36]. They reported that TCA does not affect the push-out bond strength of these calcium silicate-based cements. Furthermore, a current study about the future directions of root resorptions did not advise to use of TCA on ECR repair [35]. In the light of all this information, TCA was not preferred to use.

The power of this study was hidden in the pilot study. Because there was no similar research in the literature, performing a pilot study was a must. The depth and size of ECR cavities were determined and then standardised according to the results of this pilot study. ECR cavity was adjusted according to specific 3D classification. In addition, the mesiodistal and buccopalatal diameters of the roots were standardised by discarding in the situation of a difference of %20 from the mean. Besides, a loading angle of 135° was applied to stimulate the average angle of contact between maxillary and mandibular incisors in class I occlusion [37].

Under the limitations of this study, Biodentine may be recommended for repairing ECR cavities that extend to the pulp space. However, it should be noted that the results of this study should be carefully adapted to

clinical practice, as the clinical settings of loading force to teeth are more complex. In addition, microleakage, coloration and bond strength of the restoration materials must be taken into account. Future researches are needed to determine the most suitable bioactive material for the repair of resorption cavities of different classifications.

AUTHOR CONTRIBUTION

BA contributed to conception, design, data acquisition, analysis and interpretation, drafted and critically revised the manuscript; YŞU contributed to design, data analysis and interpretation and critically revised the manuscript; ASG contributed to design, data analysis and interpretation and critically revised the manuscript. All authors gave final approval and agreed to be accountable for all aspects of the work.

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ETHICS STATEMENT

The study protocol was approved by the Ethic committee of Bezmialem Vakıf University (Approval no: 2021/243).

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