Evaluation of Fracture Strength after Repair of Cervical External Resorption Cavities with Different Materials

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ABSTRACT

Introduction: The aim was to evaluate the stress distributions on dentin and repair materials caused by static force applied to teeth, with cervical external root resorption (CER) after repair with different materials using finite element analysis. **Methods:** This study was performed with the 3-dimensional finite element analysis method. Access cavity, root canal cavity dimensions, and supporting tissues other than cementum were modeled in the maxillary central tooth. The CER cavity was created on the labial side of the tooth model. The coronal side of the resorption cavity was restored with composite, and the radicular side with different materials (MTA, Biodentine, BioAggregate, calcium-enriched cement [CEM], glass ionomer cement [GIC], and resin-modified glass ionomer cement [RMGIC]). A static force of 300 N was applied to the palatal surface of the crown at an angle of 135° to the long axis of the tooth. The stress distributions in dentin and repair materials were analyzed. **Results:** The highest stress in dentin was seen in the fFigmodel with unrepaired CER. In the models repaired with MTA, GIC, and RMGIC, von Mises stress values in dentin were greater than for repairs with Biodentine, BioAggregate, and CEM materials. The von Mises stress on the repair materials applied to the root were highest for the BioAggregate material. This was followed by CEM, Biodentine, MTA, RMGIC, and GIC materials, respectively. **Conclusion:** The repair of CER in the tooth significantly decreased the stress values in dentin. Biodentine, BioAggregate, and CEM absorbed more force and caused less stress to be transmitted to dentin compared to MTA, GIC, and RMGIC. *(J Endod 2024;50:85–95.)*

KEY WORDS

Root resorption; cervical external root resorption; finite element analysis

SIGNIFICANCE

Susceptibility to fracture in teeth with cervical external resorption is critical in terms of prognosis. This 3D FEA study highlights the significant decrease in the stress transmitted to dentin after the repair of cervical external root resorption and reveals the stress distributions according to different repair materials.

Loss that occurs in the hard tissues of teeth with the activities of odontoclastic cells is called root resorption[1]. Tooth resorption usually originates from dental trauma. Also, tooth resorption can occur as a result of tumors, chronic infections of pulpal and periodontal structures, orthodontic tooth movements and increased pressure in the periodontal ligament[2].

Cervical external root resorption (CER), common type of root resorption, is an irreversible event that begins with cell lysis in the cementum or cementodentinal junction of the teeth[3]. Early diagnosis of this type of resorption, which is characterized by cervical location, destructive and progressive structure, is often difficult in the clinic and it may result in serious loss of tooth structure[4,5]. It usually begins asymptomatically and is detected incidentally during clinical or radiographic examination[5].

There are various treatment options for CER, such as internal approach, external approach, periodic follow-up, and extraction[6]. Treatment depends on many factors such as the extent of resorption, peripheral spread, proximity to the root canal, degree of pulp involvement, and accessibility to the resorption area[6,7,8]. In their classification using CBCT, Patel et al[8]. took into account the proximity of the lesion to the root canal, its height, and its circumferential spread. Thus, they clarified CER treatment by classifying in 3 dimensions.

In the literature, repair materials such as mineral trioxide aggregate (MTA) and Biodentine have been used for the treatment of resorption, and the formation of periodontal reattachment is possible with these materials[9-13]. In areas in contact with oral fluids, the resorption cavity can be restored with materials such as amalgam[14], composite[15], glass ionomer cement (GIC)[16], and resin-modified glass ionomer

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cement (RMGIC)[17]. Calcium-enriched cement (CEM) and BioAggregate materials are also good antifungal and antibacterial agents and can be chosen for the repair of root resorption[18-20].

In order for restorations made by the clinician to comply with the principles of oral rehabilitation, it is necessary to recognize and analyze the forces occurring in the mouth and to take into account the areas of stress and deformation that occur in the repair material used[21]. The oral environment consists of complex biomechanical systems. In finite element analysis (FEA) method, which is one of the methods used in the field of engineering for research and examination of systems, the structure to be studied is divided into very small compartments and analytically modeled, and the model is designed in the computer environment to reach the most realistic data[22,23]. Although FEA was designed for engineering systems with complex geometry, it has been adapted to dentistry biomechanics with developments in computer and software technology[24]. It is frequently used in orthodontics, endodontics, implantology, and prosthesis research[25-28].

In this study, the aim was to evaluate the von Mises stress distributions on dentin and repair materials as a result of the static force applied to models after CER cavities in the upper central tooth modeled with FEA were repaired with different materials.

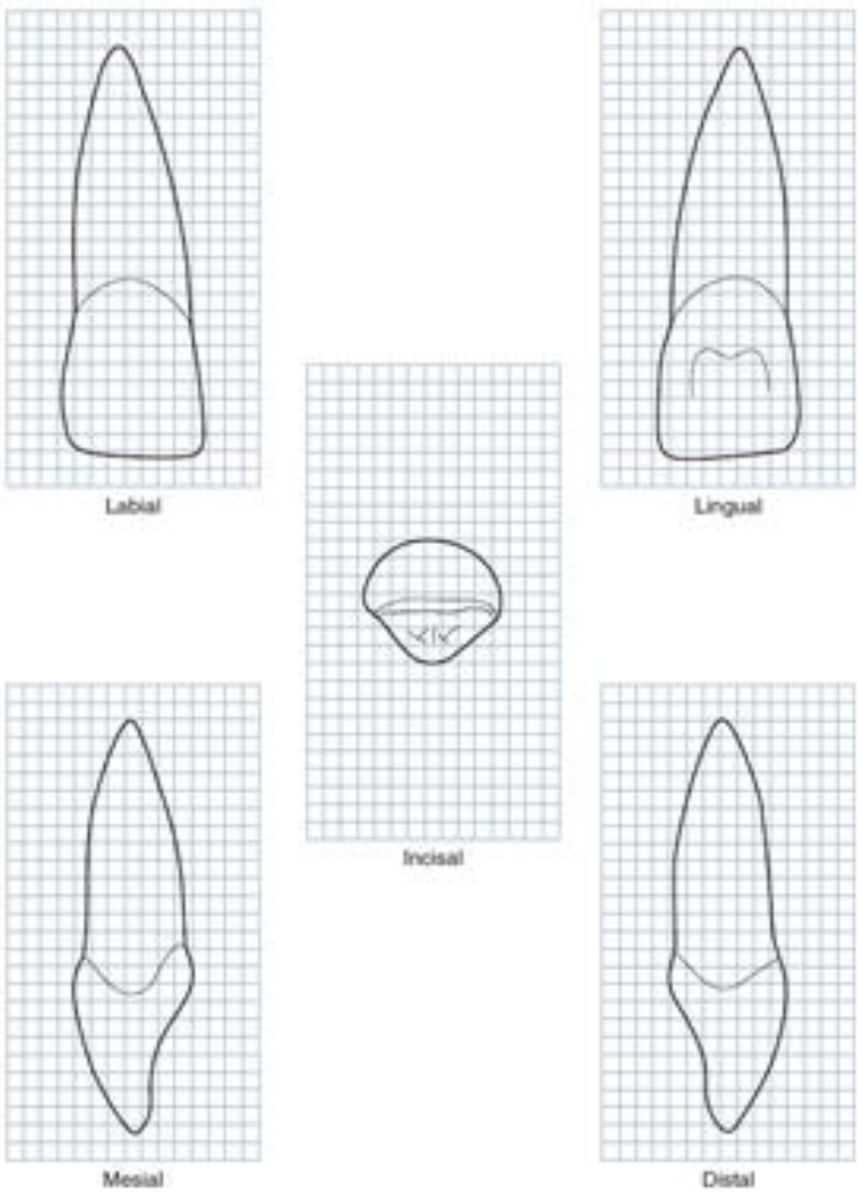

FIGURE 1 – Views of maxillary central teeth in Wheeler's dental atlas[29].

MATERIALS AND METHODS

In this study, static linear analysis was performed with the 3-dimensional FEA method. It was reported that cervical external root resorption is most common in the maxillary central teeth[14]. Therefore, the maxillary central tooth was used as a model in this study. For modelling, images taken from different angles of the upper central incisor in the Wheeler dental atlas were used[29] (Fig. 1). A 3-dimensional finite element model was created using the Rhinoceros 4.0 program. The first model represents a healthy upper central incisor (Fig. 2*A*).

The entrance cavity design was created using images from Cohen's Pathways of the Pulp.[30] The dimensions of the root canal cavity were created with a taper of 4% and an apical diameter of 0.40 mm and completed with gutta percha. A 2-mm-thick flowable composite was used as the base, and the remaining space was filled with condensable composite (Fig. 2*B*). Considering that the tooth and the supporting structures around it will resist as a whole as a result of applying force to the created model, periodontal ligament and bone (cortical and cancellous bone) were also modeled together with the tooth in this study.[31] Due to the thin structure of the cementum, there is no significant difference between it and dentin in terms of modulus of elasticity[32-34]. Therefore, cement was neglected and not modeled in the FEA model (Fig. 2*C*).

The aim was to create a CER cavity on the labial side of the model with features in the 3 bp category according to Patel's classification. For this purpose, an elliptical sphere was formed that contacted the root canal at a single point (Fig. 2*E*). When the sphere was cut by a line passing through the apex of the enamel-cementum border in the labial and palatal regions, its height in the coronal direction was 3 mm, and its height in the radicular direction was 4 mm (Fig. 2*F*). The elliptical sphere volume was then removed from the tooth structures and the CER cavity emerged (Fig. 2*G*).

When cervical external root resorption is not treated, it progresses and pockets form in the adjacent periodontal tissues, and destruction occurs in the associated bone at the same time[35,36]. In the current study, 2-mm high bone resorption was modeled in parallel with the radicular extension of resorption in models with cervical root resorption (Fig. 2*D*).

The resorption cavity in the model was examined by applying different restoration materials in the computer environment. The coronal side of the resorption cavity was

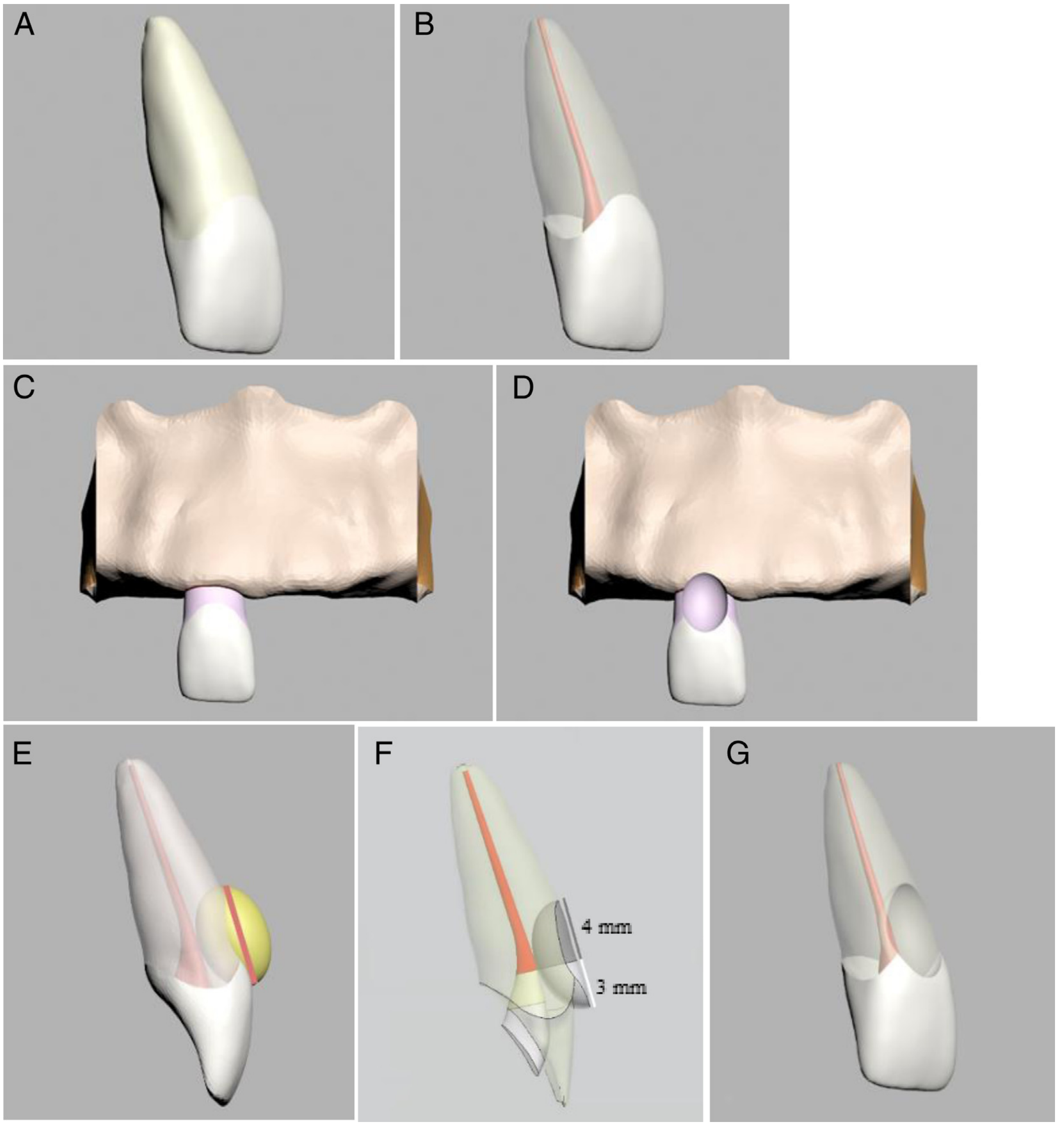

FIGURE 2 – (*A*) Healthy maxillary central tooth. (*B*) Maxillary central tooth with root canal treatment. (*C*) Maxillary central tooth with root canal treatment and supporting tissues. (*D*) Maxillary central teeth and supporting tissues with CER cavity. (*E*, *F*, *G*) CER cavity creation steps. CER, cervical external root resorption.

restored with composite, and the radicular side with different materials (MTA, Biodentine, BioAggregate, CEM, GIC and RMGIC), and a total of 8 models, including control models, were created.

Elastic modulus and Poisson ratios of all modeled teeth, support tissues (enamel, dentin, periodontal ligament, cortical bone, cancellous bone) and materials used were transferred to the FEA program (Table 1).

To simulate the bite force, a static force of 300 N[47-49] was applied to the palatal surface of the crown, 2 mm[50] below the incisal edge, at an angle of 135°[47,51] to the long axis of the tooth. Then, the stress distributions on each model were analyzed (Fig. 3). Von Mises stresses occurring in dentin and repair materials were evaluated.

RESULTS

In the study, the stress absorption of repair materials against static force and the stress distributions in dentin were evaluated with FEA using standard models. When von Mises stresses in dentin were evaluated, the highest (258.222 GPa) stress was seen in the model with unrepaired cervical resorption. The lowest stress value (100.679 GPa) was in the healthy central tooth model (Fig. 4, Table 2).

In teeth restored with Biodentine, BioAggregate, and CEM materials, von Mises stress values in dentin were similar. Models repaired with MTA, GIC, and RMGIC also exhibited similar stress distributions, but resulted in greater stress transmission to dentin than the other 3 materials (Fig. 5, Table 2).

The von Mises stress on the repair materials applied to the root occurred at the highest value in the BioAggregate material. This was followed by CEM, Biodentine, MTA, RMGIC, and GIC materials, respectively. MTA, GIC, and RMGIC materials exhibited very close stress values and no significant difference was found between them when the stress distributions were examined visually (Fig. 6). Biodentine and CEM materials had similar stress values and no significant difference was detected between them when compared based on their visual color distribution. Although the BioAggregate material exhibited

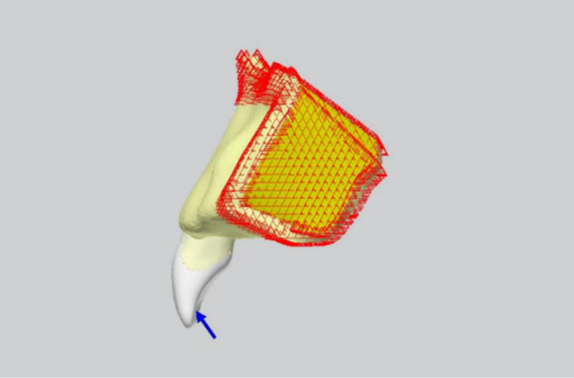

FIGURE 3 – Direction and magnitude of the applied force.

a stress distribution image close to that of Biodentine and CEM materials, more stress occurred in the interface contact zone with the composite (Fig. 6, Table 2).

Composite material, which is the repair material used in the coronal direction of resorption, absorbed more stress and transmitted less stress to dentin when used with Biodentine, BioAggregate, and CEM. When MTA was used with GIC and RMGIC, more stress was transmitted to dentin (Fig. 7, Table 2).

DISCUSSION

Diagnosis and treatment of CER is a clinically difficult condition. This can lead to tooth loss as a result of misdiagnosis and inappropriate treatments[52]. An accurate diagnosis, treatment with the appropriate material selection and long-term follow-up are important to keep the tooth in the mouth[53]. Another issue to be considered in material selection is the decrease in fracture resistance of teeth in cases with advanced resorption. The restorative material to be used for treatment should have mechanical properties that support the tooth and surrounding tissues and strengthen the tooth structure as much as possible[54]. In line with the purpose of the study, the aim was to select the appropriate material for CER cavities, to see the variation in how much stress is transmitted to the dentin and its effect on tooth fracture by using FEA.

The maximum load that teeth can withstand during function is determined by breaking strength tests. However, an important disadvantage of these tests is that they are performed using extracted teeth[55,56]. It is difficult to provide ideal standardization in extracted teeth. Various parameters such as anatomy and morphology of the tooth, chemical content, degree of dehydration and mineralization differ. In addition, these tests do not provide information about the stresses that occur as a result of the applied force and are not sufficient for the evaluation of restorative approaches in the long term. Therefore, stress analysis methods are considered superior to fracture strength tests in determining long-term deformation[56].

Among the stress analysis methods, the FEA method has many advantages compared to other stress analysis methods. In the FEA method, the stresses occurring in any part of the model to be analyzed can be evaluated. In other stress analysis methods, the areas to be evaluated are limited. FEA can be repeated and the direction and amount of force to be applied can be changed. Thus, comparisons can be made with the application of forces in different directions and amounts[57,58]. In 3-dimensional FEA models, the dimensions, irregularities and changes in the different layers of objects can be designed in the most realistic way. In addition, three-dimensional models can be rotated as desired and viewed from different angles and perspectives[59]. For this reason, the decision was made to use FEA in the current study.

In line with the findings, CER significantly increased stress accumulation in the tooth and there was a significant decrease in stress values as a result of restoring the resorption cavity (Table 2, Figs. 4 and 5). Similarly, Bayram et al.[60] and Günay[61] found that the fracture resistance of teeth with cervical resorption decreased, and the fracture resistance increased with repair of resorption.

In the untreated resorption model, the highest von Mises stress in dentin was detected in the middle part of the resorption cavity. This region is where root fractures may start due to the deterioration of dentin and bone integrity as a result of resorption. Furthermore, this area includes part of the so-called pericervical dentin. The pericervical dentin region is located approximately 4 mm above and below the top of the alveolar crest. This is a region where forces are concentrated and is responsible for tooth fracture, so it is very important to protect this region[62]. With the repair of the resorption cavity, the highest stress value in the dentin shifted toward the apical border of the cavity in all models. This situation can be interpreted as follows; the restorative materials provided mechanical support to the tooth, the stresses caused by the incoming forces shifted from the resorption area, which was prone to fracture, to the location of intact tooth and supporting tissues,

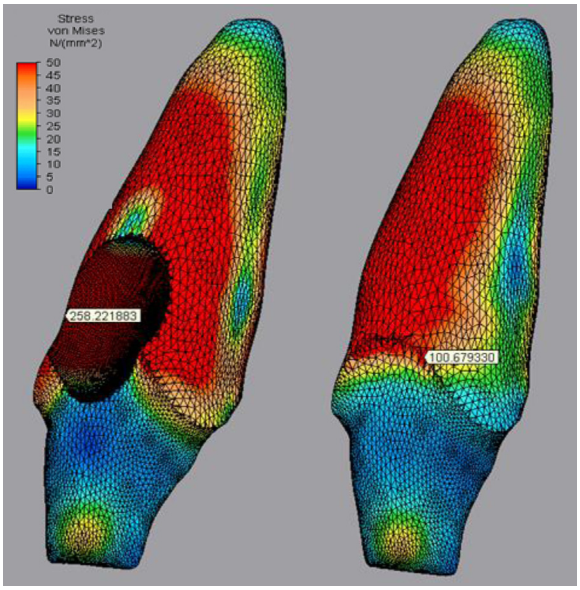

FIGURE 4 – Von Mises stress distributions in a healthy central tooth and a central tooth with CER cavity. CER, cervical external root resorption.

TABLE 1 - Modulus of Elasticity and Poisson Ratios of Tooth, Support Tissues, and Restorative Materials Used

Materials	Elasticity modulus (E) (GPa)	Poisson ratio (v)	References
Enamel	84.1	0.33	37
Dentine	18.6	0.32	37
Pulp	0.003	0.45	38
Periodontal ligament	0.0689	0.45	39
Cortical bone	13.7	0.30	40
Spongiosa bone	1.37	0.30	40
Gutta-percha	0.00069	0.45	41
Composite	16.4	0.28	34
Flowable composite	5.3	0.28	42
Mineral trioxide aggregate (MTA)	11.7	0.31	34
Biodentine	22	0.30	34
BioAggregate	26	0.25	43
Calcium-enriched cement (CEM)	24.87	0.33	44
Glass ionomer cement (GIC)	10.8	0.30	45
Resin-modified glass ionomer cement (RMGIC)	10.86	0.30	46

and the fracture resistance of the tooth increased.

The modulus of elasticity values for Biodentine, BioAggregate, and CEM materials are close to each other and higher than MTA, GIC, and RMGIC. Materials with higher modulus of elasticity provided more stress absorption and transmitted less stress to dentin (Fig. 6). Li et al.[63], Gürbüz et al.[64], and Akdoğan[65] also obtained similar results in their studies. According to the study by Gürbüz et al.[64], the stress on dentin decreased as the elasticity modulus of the materials used increased. However, they stated that if the difference in modulus of elasticity between dentin and the material increases too much, there may be failure in the structure and therefore the most suitable material is the material whose elasticity modulus is closest to the elasticity modulus of dentin[64]. In our study, materials with higher modulus of elasticity (Biodentine, BioAggregate, CEM) transmitted less stress to the dentin. However, the stress in the BioAggregate material, which had a higher modulus of elasticity than Biodentine and CEM, increased in the interface area where it was in contact with the composite (Fig. 6). This situation may cause failures that may occur in the interface. For this reason, in order to prevent tooth breakage and also failures at the material interface, materials with a modulus of elasticity close to that of dentin should be chosen.

Aslan et al.[38] repaired different iatrogenic root perforations (strip perforation, furcation perforation, perforation during post cavity preparation) in mandibular molar teeth with MTA and Biodentine and analyzed the results with FEA. According to the results of the study, Biodentine models exhibited lower von Mises stresses than MTA models. Akgün[66] examined the stress distributions via FEA by modeling external root resorptions in the maxillary central tooth with different sizes and locations and repairing them with GIC, MTA, and Biodentine. According to the results of the study, the use of Biodentine and MTA reduced stress accumulation in the tooth more than the use of GIC. Biodentine caused less stress accumulation in dentin than MTA. Nagas et al.[67] reported in their *in vitro* studies that Biodentine made the tooth more resistant to tooth fracture than MTA. In parallel with these studies, in the current study, Biodentine material transmitted less stress to dentin than MTA. However, unlike Akgün's study, there was no significant difference in stress distribution between GIC and MTA.

Eram et al.[43] used MTA, Biodentine, and BioAggregate as apical plug and canal filling material in immature upper central teeth and evaluated the stress distributions with FEA. According to the results obtained, tooth models using MTA had the lowest stress and thus the highest fracture resistance when used as both apical plug and canal filling material. This was followed by models treated with Biodentine and BioAggregate, respectively. Belli et al.[34] compared MTA, Biodentine and $Ca(OH)_2$ in their FEA study of immature premolar teeth. They used these three materials as canal filling material and coronal barrier. They also evaluated MTA and Biodentine use as apical plugs. As a result of the force applied to the 3-dimensional models at an angle of 135° with a value of 300 N, less stress occurred on the dentin in the models with MTA compared to the models with Biodentine. Girish et al.[68] used MTA and Biodentine for the treatment of apexification and filled the entire root canal in an *in vitro* study examining the fracture resistance of immature mandibular premolar teeth. They stated that MTA and Biodentine exhibited similar compressive strength and did not make a significant difference in terms of tooth breakage. These results contradict the present study.

Grayli et al.[69] used MTA and CEM as apical barriers and compared their fracture resistance *in vitro*. No significant difference was found between the two materials in their study. Sarraf et al.[70] used MTA, Biodentine, and CEM as root fillings in immature cattle teeth and compared their fracture resistance. CEM increased the fracture resistance of teeth less than MTA and Biodentine. Contrary to these studies, according to the stress distribution results obtained from the present

TABLE 2 - Von Mises Stress Values

Models	Stress in dentin (GPa)	Stress on repair material in radicular direction (GPa)	Stress on repair material used in coronal direction (composite) (GPa)
Healthy central tooth	100.679	—	—
Central tooth with CER	258.222	—	—
MTA model	167.183	70.525	50.980
Biodentine model	161.808	85.695	54.197
BioAggregate model	164.718	97.292	53.233
CEM model	161.212	89.416	54.626
GIC model	167.211	69.877	50.020
RMGIC model	167.176	69.994	50.054

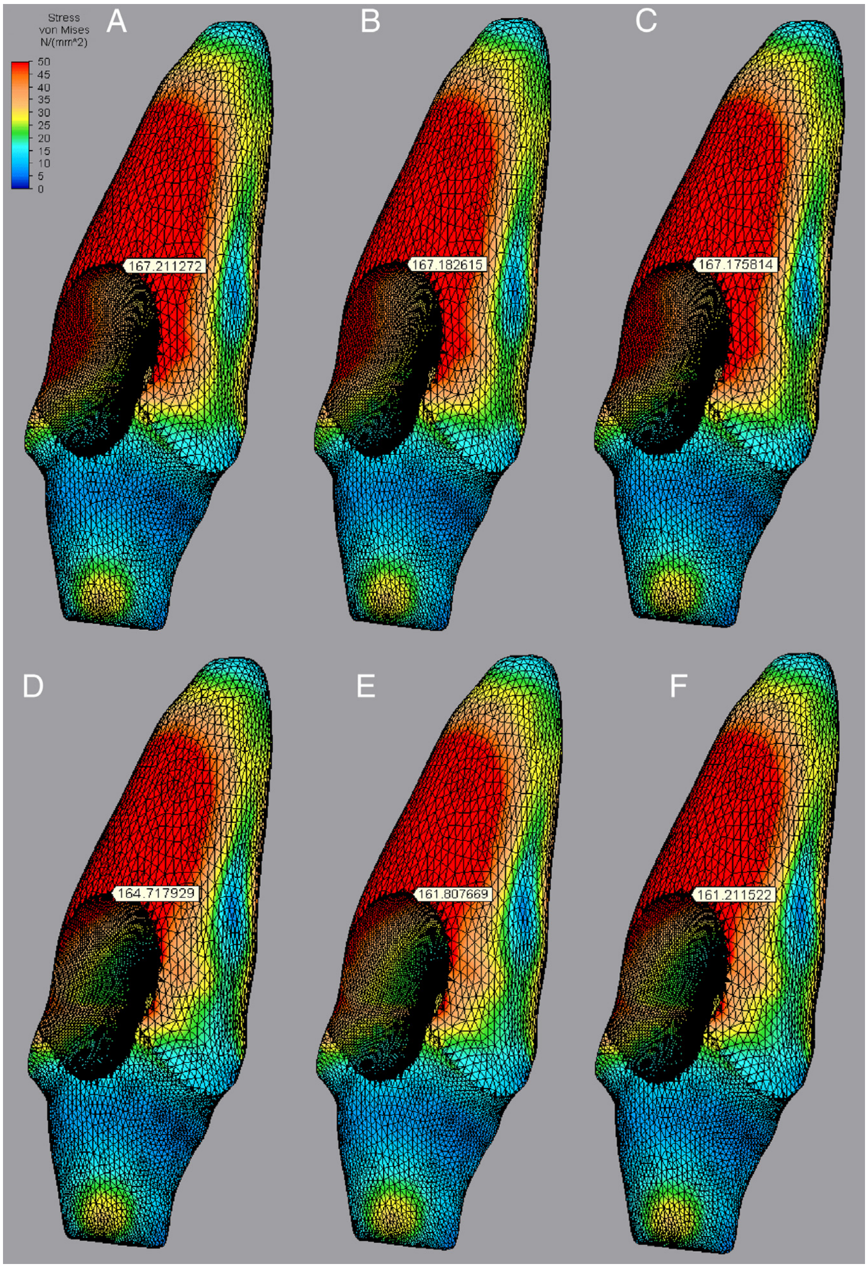

FIGURE 5 – Von Mises stress distributions in dentin. (*A*) Model 4 (MTA). (*B*) Model 8 (GIC). (*C*) Model 9 (RMGIC). (*D*) Model 5 (Biodentine). (*E*) Model 6 (BioAggregate). (*F*) Model 7 (CEM). CEM, calcium-enriched cement; GIC, glass ionomer cement; MTA, mineral trioxide aggregate; RMGIC, resin-modified glass ionomer cement.

study, CEM and Biodentine increased the fracture resistance of the tooth more than MTA. In support of the current study, Demircan, in his FEA study modeling regenerative endodontic treatment in an immature permanent central tooth, showed that there was less stress accumulation in dentin in Biodentine and CEM models compared to MTA models.

Shubhashini et al.[71] repaired teeth with class V cavities with different materials in their study using the FEA method and examined the stress distributions. According to the results of the study, the micro-filled composite had the best performance. This was followed by flowable composite, GIC and RMGIC. Unlike the current study, in the study by Shubhashini et al., GIC caused less stress on dentin than RMGIC. In the present study, the stress distributions created by GIC and RMGIC are very similar and there was no significant difference between them.

The different results between the current study and other studies in the literature may be due to the type of study, differences in dental models and treatment approaches in the studies. Many factors such as the regions where the materials used in the studies are placed, the tissues surrounding the material, the applied forces and direction, the differences between the elastic modulus values of the materials, the type of tooth and the stage of tooth development may have played a role in the different results of the studies.

For the restoration of CER, esthetic concerns come to the fore as well as function due to position. However, failures have occurred in the use of adhesive resin for restoration of cavities whose cervical margin extends below the enamel-cementum junction[72,73]. The outer layer of cement is hypomineralized and superorganic and does not allow micro-retention of adhesive materials, even after acid etching[74]. Histological and structural differences make the cemented adhesion of the composite weaker and less predictable than enamel[75]. Clinicians have used combined treatment options in the presence of both esthetic needs and cavities extending toward the root surface[76,77]. In this way, the stresses in the composite, which is the repair material used in the coronal direction, and the stresses transmitted to the dentin were found to be parallel with the repair material used in the radicular direction (Fig. 7). The composite exhibited behavior similar to the material it was used in combination with.

In reality, teeth are exposed to many complex force components such as parafunctional forces in the mouth[78]. However, the loading condition applied in the present study lacks this complexity. Therefore, testing of only one load condition is one of the limitations of this study.

Cervical resorption can occur in any region of the cervical tooth, but only resorption occurring on the buccal face was modeled in this study. Although the dimensions of the resorption cavity vary widely, it does not actually have a smooth surface as in the current model. Therefore, there is a need to test resorption cavities with different surface models in different sizes and locations in further studies.

In dynamic and complex tissues such as dentin, the effect of canal filling materials on the microhardness of dentin may vary over time[79]. However, the results obtained with FEA reflect the structural properties of the modeled teeth and support tissues at the time of application. Therefore, although these results cannot be directly reflected in clinical practice, they provide the opportunity to compare materials under standard conditions and may provide a preliminary idea to be supported by further clinical and experimental studies.

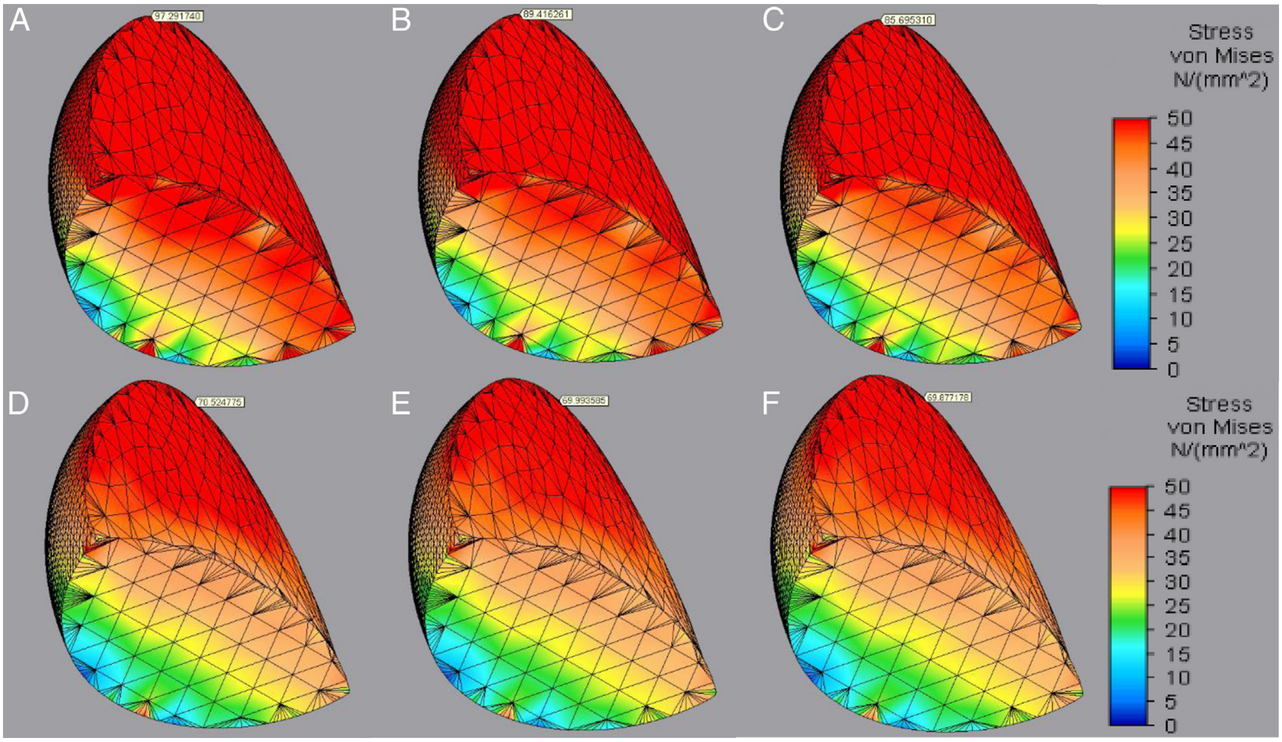

FIGURE 6 – Von Mises stress distributions of repair materials. (*A*) BioAggregate. (*B*) CEM. (*C*) Biodentine. (*D*) MTA. (*E*) RMGIC. (*F*) GIC. CEM, calcium-enriched cement; GIC, glass ionomer cement; MTA, mineral trioxide aggregate; RMGIC, resin-modified glass ionomer cement.

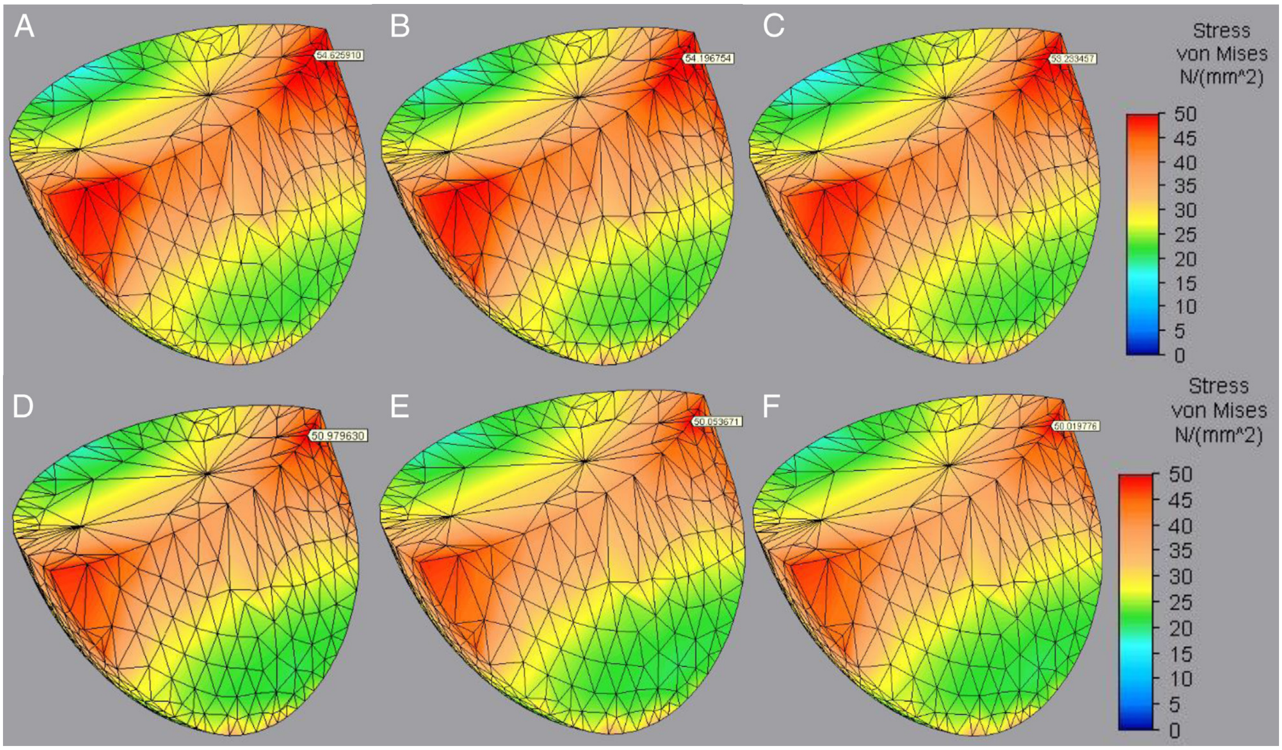

FIGURE 7 – Von Mises stress distributions on the repair material in the coronal direction (composite). (*A*) CEM. (*B*) Biodentine. (*C*) BioAggregate. (*D*) MTA. (*E*) RMGIC. (*F*) GIC. CEM, calcium-enriched cement; GIC, glass ionomer cement; MTA, mineral trioxide aggregate; RMGIC, resin-modified glass ionomer cement.

CONCLUSIONS

- The presence of CER in the tooth significantly increased the stress on the dentin. Repairing the resorption cavity significantly reduced the stress transferred to dentin.
- As a result of the repair of the resorption cavity, the highest stress point in dentin replaced toward the apical border of the cavity where dentin integrity was better in all models.
- Of the repair materials, Biodentine, BioAggregate, and CEM absorbed more force and caused less stress to be transmitted to dentin compared to MTA, GIC, and RMGIC. Therefore, BioAggregate, Biodentine, and CEM may be preferred as alternatives to other tested materials for the treatment of cervical external root resorption.
- Material with higher modulus of elasticity distributes the stress more homogeneously and accumulates stress within itself compared to materials with lower elasticity modulus, causing less stress to be transmitted to the surrounding tissues. However, as the difference between the elastic modulus of the material and the dentin increases, the stresses accumulated at the material interface increase. Therefore, materials with modulus of elasticity closest to dentin should be preferred.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Merve Çoban Öksüzer: Writing – review & editing, Investigation, Investigation, Writing – original draft. **Ahter Şanal Çıkman:** Supervision, Methodology, Writing – review & editing.

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