Journal of Oral Biology and Craniofacial Research 14 (2024) 415–422

Contents lists available at ScienceDirect

Journal of Oral Biology and Craniofacial Research

journal homepage: www.elsevier.com/locate/jobcr

Stress distribution in endodontically treated external cervical resorption lesions restored with MTA and biodentine – A finite element analysis

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ARTICLE INFO

Keywords:
Biodentine
External cervical resorption
Finite element analysis

ABSTRACT

Introduction: Root resorption poses a significant challenge in dental practice, with external cervical resorption (ECR) being a common manifestation. ECR is often asymptomatic until advanced stages, complicating its diagnosis and management. Various factors contribute to its etiology, ranging from trauma to orthodontic treatment. The classification system proposed by Patel et al. (2018) offers a comprehensive framework for characterizing ECR lesions based on location and extent. Treatment strategies for ECR involve a combination of endodontic intervention and restorative techniques, with bioactive materials like mineral trioxide aggregate (MTA) and Biodentine emerging as promising options. However, the biomechanical behavior of teeth restored with these materials in the context of ECR remains underexplored.

Materials and methods: This study utilized finite element analysis (FEA) to assess stress distribution in teeth with simulated ECR lesions of varying sizes and locations, restored with MTA or Biodentine. Three-dimensional models of maxillary central incisors were generated based on CBCT scans, incorporating periodontal ligament and surrounding bone structures. Eight experimental models representing different ECR configurations were created and subjected to FEA using Optistruct software based on dimensional classification given by Patel et al., in 2018, A70 M & A70B: 1Ap, A130 M & A130B: 1Bp, B70 M & B70B: 2Ap, B130 M & B130B: 2Bp. All the models were tested for stress distribution by restoring the lesions with either M: MTA or B: Biodentine. Oblique load of 100 N was applied at 45°angle to the long axis 2 mm lingual to incisal edge. vonMises Stress distribution in enamel, dentine, restoration and at all the interfaces were observed.

Results: The analysis revealed that both MTA and Biodentine restorations exhibited uniform stress distribution around ECR lesions, with no significant differences based on lesion location or size. Maximum stress concentrations were observed around the restorations, particularly in subcrestal lesions. However, overall stress levels were comparable between MTA and Biodentine restorations, indicating similar biomechanical performance.

Conclusion: Finite element analysis provides valuable insights into the biomechanical behavior of teeth with ECR lesions restored with MTA and Biodentine. Both materials exhibit similar stress distribution patterns and offer adequate reinforcement against mechanical forces. Clinicians can confidently utilize MTA or Biodentine in the management of ECR, considering their favorable biomechanical properties and clinical outcomes. Further research is necessary to validate these findings and optimize treatment protocols for ECR.

1. Introduction

Root resorption can be physiological or pathological leading to loss of dental hard tissue. Pathological root resorption can be divided into internal root resorption and external root resorption based on location.[1]

The lesion in case of external cervical resorption (ECR) is usually not visible clinically as it begins below the epithelial attachment at the cervical third of the root. The defect has a circumferential spread and extends horizontally and vertically, not involving the pulp canal space in the initial stage. Therefore, the tooth remains asymptomatic until there is pulpal involvement making early diagnosis difficult.[2] The exact etiology of ECR is unknown however many predisposing factors have been proposed by several authors like orthodontic treatment, intracoronal bleaching, trauma, periodontal therapy, surgical procedures,

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https://doi.org/10.1016/j.jobcr.2024.04.012
Received 29 February 2024; Received in revised form 25 April 2024; Accepted 30 April 2024
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intracoronal restorations, bruxism, developmental defects and systemic diseases, malocclusion, extraction of a neighbouring tooth, autotransplantation, periodontitis, etc[3] or according to some a completely inflammatory reaction.[4]

External cervical root resorption has been further classified using Cone Beam Computed Tomography (CBCT) by Patel et al.[5] in 2018 which takes into account height (1: at Cemento-Enamel Junction (CEJ) level or coronal to the bone crest (supracrestal), 2: extends into the coronal third of the root and apical to the bone crest (subcrestal), 3: extends into the mid-third of the root, 4: extends into the apical third of the root), circumferential spread (A: ≤90° B: ≤180 °C: ≤270° D: >270°) and proximity to the root canal (d: lesion confined to dentin, p: probable pulpal involvement).[5]

Clinically visible lesions may appear as a small defect at the gingival margin or pink discoloration in the crown consequently resulting in cavitated lesions.[6] Radiographically, radiolucency with irregular margins or a uniform radiolucency centred over the root can be seen. Extensive lesions can appear mottled.[4]

Small lesions with minimal or no pulpal involvement have the most favorable prognosis. Depending on the extent and the level of the lesion, an external or internal approach is taken. In supracrestal lesions with no pulpal involvement, granulomatous tissue is curetted followed by restoration. The lesions with greater extent can be treated with pulp capping,either indirect or direct with the help of bioactive materials like Biodentine and Mineral Trioxide Aggregate (MTA).[7]

Inaccessible subcrestal lesions and large lesions with extensive and irreversible pulp involvement require internal approach. After endodontic treatment, the cavity can be restored with composite or Glass Ionomer Cement (GIC). Alternatively, the resorptive cavity can be restored with a bioactive cement through an internal approach. Bioactive cements have shown to hinder the osteoclastic action and remains the preferred materials for restoration of External Cervical Resorptive lesions by virtue of their high pH.[7,8] Ideal repair material includes MTA that provides a sufficient radiopacity, good seal, high pH, low solubility and is well tolerated by periradicular tissue. It has also been shown to induce odontoblastic differentiation.[8]

Biodentine is a more recently developed bioactive material that exhibits excellent biocompatibility. The sealing ability is equivalent to that of glass ionomer cement and provides better consistency and faster setting time (12 min when compared to setting time of 140–180 min of MTA).[9]

In situations where both internal (endodontic intervention), as well as external (surgical) approaches, are not feasible, intentional reimplantation can be done. Lastly, in cases where none of the above-stated modalities can be used, the final option remains extraction of the affected tooth followed by prosthetic rehabilitation.[7] Removal of tooth structure during endodontic treatment along with loss of hard tissue due to resorptive defect, affects the mechanical behaviour of these teeth. This leads to overall weakening teeth even if they are restored with appropriate dental materials.[10]

It has been reported that oblique stresses are more deleterious in nature when compared to lateral forces,[11] with loss of cervical dentin being a critical factor that impacts and increases the risk of fracture of endodontically treated tooth.[12] This makes evaluation of stress distribution important in cases of external cervical resorption as large lesions have to be restored. Finite element analysis (FEA) has proven to be of use in dentistry as it can be used for evaluating the mechanical properties of involved materials and human tissue that would have been challenging to analyse in vivo.[11]

To the best of our knowledge finite element analysis has not been used till date to assess the stress distribution patterns in case of external cervical resorption repaired using MTA and Biodentine.

2. Materials and methods

This study was registered and approved by Ethical Committee under the protocol number XXXXXXX/IIEC/2020-23/CONS/05. This study was conducted in accordance with the Declaration of Helsinki.

2.1. Obtaining model geometry

A prototype of Maxillary Central Incisor was obtained by scanning of the tooth through CBCT. The scanned DICOM file was processed through Slicer software and a hollow 3D model of Maxillary Central Incisor was made in.stl (stereolithography) format. The.stl (stereolithography) format file generated was imported into computer-aided software (Rhino 3D). The file in.stl format was converted to.iges format and a hollow model was converted to a solid base model with its supporting structures periodontal ligament, cortical bone, trabecular bone.

The dimensions of the 3D model of central incisor were: overall length 21 mm, 9.4 mm crown, and root length of 11.6 mm and supporting structures including periodontal ligament (PDL) was 0.2 mm in thickness between the root dentin and cortical and cancellous bone and cortical bone of 2 mm.

Following this based on 3-dimensional classification given by Patel et al.[5] in 2018, 8 experimental models simulating external cervical resorption were designed. (Table 1).

Model 1: Tooth with supracrestal lesion of 2 mm height and 70° circumferential spread restored with MTA (A70 M)

Model 2: Tooth with supracrestal lesion of 2 mm height and 70° circumferential spread restored with Biodentine (A70B)

Model 3: Tooth with supracrestal lesion of 2 mm height and 130° circumferential spread restored with MTA (A130 M)

Model 4: Tooth with supracrestal lesion of 2 mm height and 130° circumferential spread restored with Biodentine (A130B)

Model 5: Tooth with subcrestal lesion of 2 mm height and 70° circumferential spread restored with MTA (B70 M)

Model 6: Tooth with subcrestal lesion of 2 mm height and 70° circumferential spread restored with Biodentine (B70B)

Model 7: Tooth with subcrestal lesion of 2 mm height and 130° circumferential spread restored with MTA (B130 M)

Model 8: Tooth with subcrestal lesion of 2 mm height and 130° circumferential spread restored with Biodentine (B130B)

Root canal treatment was simulated with apical preparation of size #80. The space was filled using Gutta percha virtually by the software till the apical extent of the lesion. Above this the lesion was filled using the experimental biomaterials (MTA and Biodentine). The access cavity was also restored virtually using the software by nanohybrid composite resin.

2.2. FEM analysis

The Geometric models were prepared and finite element mesh was superimposed on it by a way of manual meshing. The intersection of sides of elements is called “nodes”, where elements are connected. The selection of elements type and discretization of solution domain constitute first step in finite elements solution procedure. Second step is assigning material properties to respected elements. Final step is defining loading conditions and introduction of boundary conditions. All the eight models were tested for stress distribution.

The assembled models were imported to Optistruct (Altair). All the elements were assigned their respective material properties (Young’s modulus and Poisson’s ratio). (Table 2). Thus 3-dimensional finite element models containing elements and nodes representative of root canal treated maxillary central incisor with different classes of external cervical resorption were created.

The Meshing framework to generate finite element models was done using Hypermesh (Altair).

The restoration-tooth interfaces in all the models were considered perfectly bonded. To simulate occlusal contacts in centric relation, oblique load of 100 N was applied at 45°angle to the long axis 2 mm lingual to incisal edge. Once the material properties were assigned and

Table 1
The specifications of the 8 formed models formed as per the classification given by Patel et al.(2008).

Model	Restoration	Height	Circumferential Spread	Pulpal Involvement	Level with respect to crestal bone
A70M	MTA	2 mm	70°	Yes	Supracrestal
A70B	Biodentine				
A130M	MTA	2 mm	130°	Yes	Supracrestal
A130B	Biodentine				
B70M	MTA	2 mm	70°	Yes	Extending Below the Crest of bone
B70B	Biodentine				
B130M	MTA	2 mm	130°	Yes	Extending Below the Crest of bone
B130B	Biodentine				

A70M – Supracrestal Lesion with 70°circumferetial spread filled with MTA.
A70B – Supracrestal Lesion with 70°circumferetial spread filled with Biodentine.
A130M – Supracrestal Lesion with 130°circumferetial spread filled with MTA.
A130B – Supracrestal Lesion with 130°circumferetial spread filled with Biodentine.
B70M – Subcrestal Lesion with 70°circumferetial spread filled with MTA.
B70B – Subcrestal Lesion with 70°circumferetial spread filled with Biodentine.
B130M – Subcrestal Lesion with 130°circumferetial spread with MTA.
B130B – Subcrestal Lesion with 130°circumferetial spread with Biodentine.

Table 2
Material properties of different elements.

Material	Young's Modulus (MPa)	Poison's ratio
Dentin[8]	18600	0.31
Enamel[10]	84100	0.3
PDL[8]	0.068	0.45
Gutta Percha[8]	0.14	0.45
Composite Resin[8]	16400	0.28
Biodentine[8]	22000	0.33
MTA[8]	11760	0.31
Cortical Bone[8]	13700	0.30
Spongy Bone[8]	1370	0.30

meshing was done, the nodes for load were identified and load was applied. The linear analysis was carried out using Optistruct (Altair) software under definite loading.

2.3. Stress distribution analysis

The qualitative results were represented as stress maps (the hot color represents the highest stress values, and the cold colors represent the lowest stress values); while the quantitative results was represented as various stress values. Von Mises Stress distribution in enamel, dentin, restoration and at dentin and MTA/Biodentine interface, enamel and MTA/Biodentine interface, and Composite resin and MTA/Biodentine interface were observed.

2.4. Statistical analysis

Statistical Analysis was not done is this study as it is a Finite Element Analysis Study.

3. Results

Stress analysis was done using von Mises stresses. Stress concentrations are depicted as a colour scale and numeric values obtained in MPa.

3.1. Stresses in Whole tooth

The maximum stresses were observed in the cervical region of the intact tooth. In the test models, maximum stresses were observed around the restorations.

In intra-group comparison for MTA restored lesions, subcrestal lesions showed more stress concentrations than supracrestal lesions, maximum being in B70. Biodentine models also showed similar results with subcrestal lesions showing more concentrations with maximum stresses in B70. For all the locations, stress concentrations of MTA were lesser than those of Biodentine. Lowest stress concentration was observed in A70 M (Fig. 1, Fig. 2, Fig. 3).

3.2. Stresses in enamel

The maximum stresses were observed in the cervical region of the intact tooth. In the test models, maximum stresses followed the same pattern with the stresses distributed alongside the restorations. In intra-group comparison for MTA restored lesions; maximum stresses were seen in subcrestal models, with B70 M showing the maximum stress concentration. Similar pattern was seen in the teeth restored with Biodentine, with B70B showing the maximum stress concentration.

For all the locations, stress concentrations of MTA were less compared to Biodentine (Figs. 1 and 4, Fig. 5).

3.3. Stresses in dentin

The maximum stresses were observed in the cervical region and palatal surface of the root of the intact tooth. In the test models, maximum stresses followed the same pattern. In intra group comparison for MTA restored lesions, maximum stresses were observed in B70 M, near the apical end and in A130 M at mid root level. Biodentine models also showed similar results.

For all the locations, no significant difference was seen in stress concentrations after restoration using MTA and Biodentine (Figs. 1 and 6, Fig. 7).

3.4. Stresses in restoration

In MTA restored lesions, A70 M showed least stress concentration. Similar results were seen in Biodentine with A70B showing the minimum concentration.

It can be said that even though MTA was found slightly superior in all the test models, no major difference was found between both and the stresses obtained after repair with Biodentine and MTA were comparable to each other.

4. Discussion

Treatment modalities for external cervical resorption depend on location and circumferential spread of the lesion along with the status of pulpal involvement. Smaller lesions, for example, 1Ad, 2Ad, and 2Bd according to Patel et al.[7] can be repaired through external approaches with or without endodontic treatment. Treatment modalities include the application of trichloroacetic acid (TCA) or 3–5 % Sodium hypochlorite

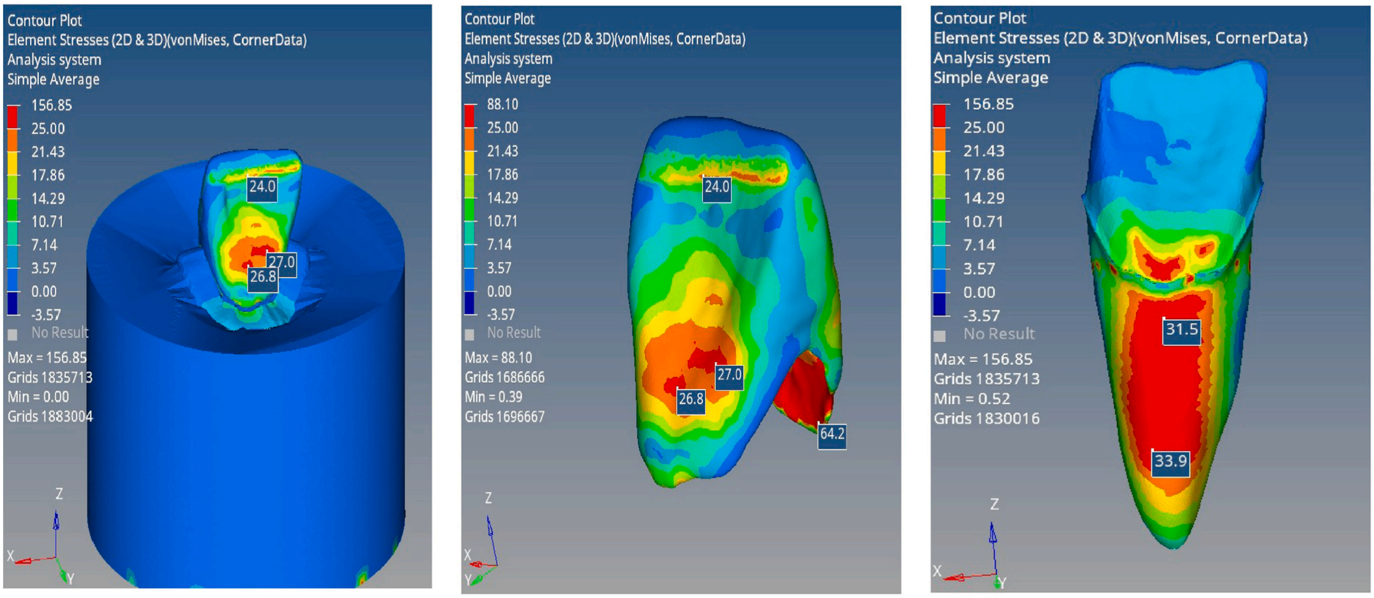

Fig. 1. Von Mises stresses in intact tooth, enamel and dentin. A 70: Supracrestal Lesion with 70°circumferential spread filled with MTA, B 70: Subcrestal Lesion with 70°circumferential spread filled with MTA.

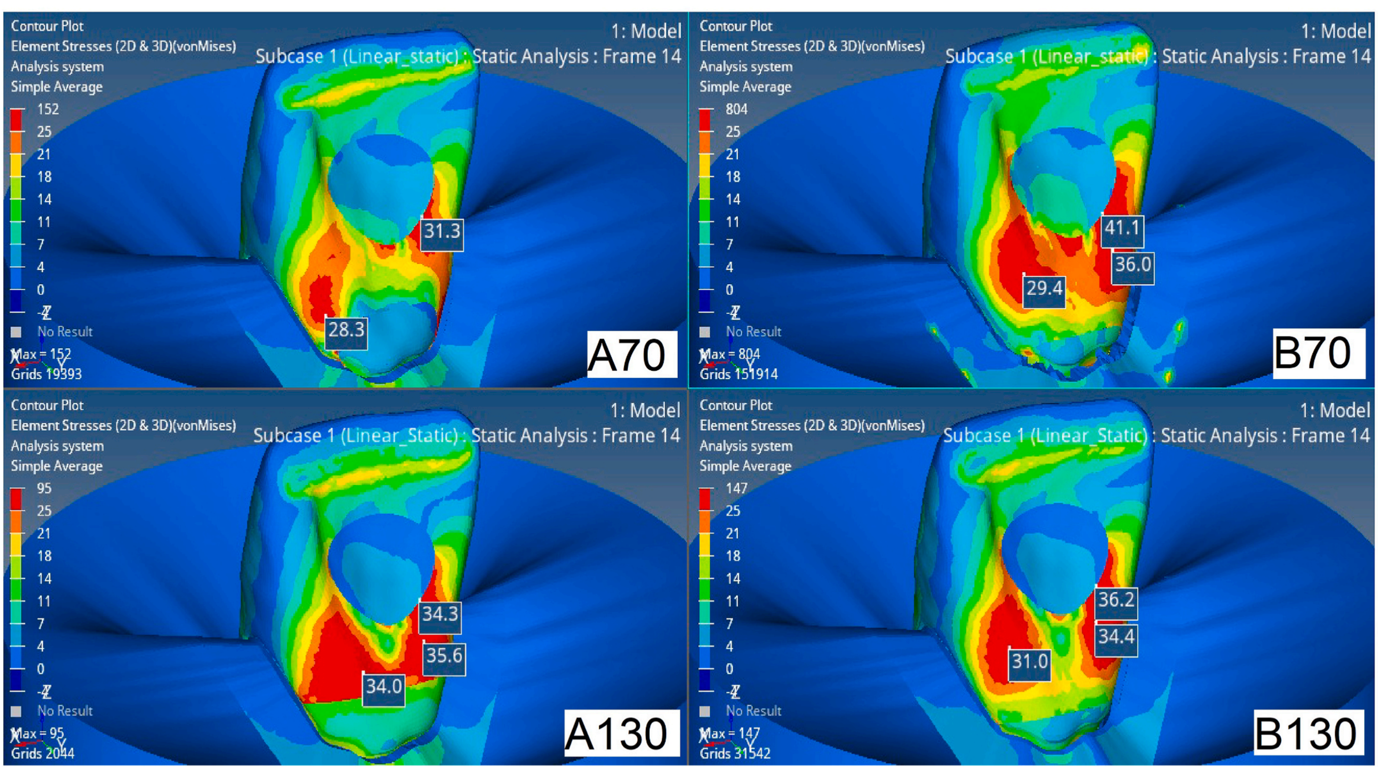

Fig. 2. Von Mises stresses in whole tooth filled with MTA. A 70: Supracrestal Lesion with 70°circumferential spread filled with MTA, B 70: Subcrestal Lesion with 70°circumferetial spread filled with MTA.

and restoration with composite or GIC. An indirect or direct pulp capping might be required for lesions with a greater extent like 1Ap, 2Ap, and 2Bp.[7]

In extensive lesions like 2Cp, 2Dp, 3Cp, and 3Dp or smaller lesions which have perforated the pulpal chamber, an internal approach i.e. endodontic treatment becomes necessary.[7] Resorptive lesions can be restored with biocompatible materials like MTA or Biodentine which provide an adequate seal, have antibacterial properties, and are well tolerated by periradicular tissues.[11]

Many case reports[2,9] have suggested a successful treatment outcome in teeth treated with MTA or Biodentine and a very few in vitro studies have evaluated the same but the biomechanical behaviour of such restored teeth particularly with large circumferential spread has not been discussed. Hence, the present study was conducted to evaluate the stress concentration in the tooth with the help of simulated models with external cervical resorption in maxillary central incisor at different

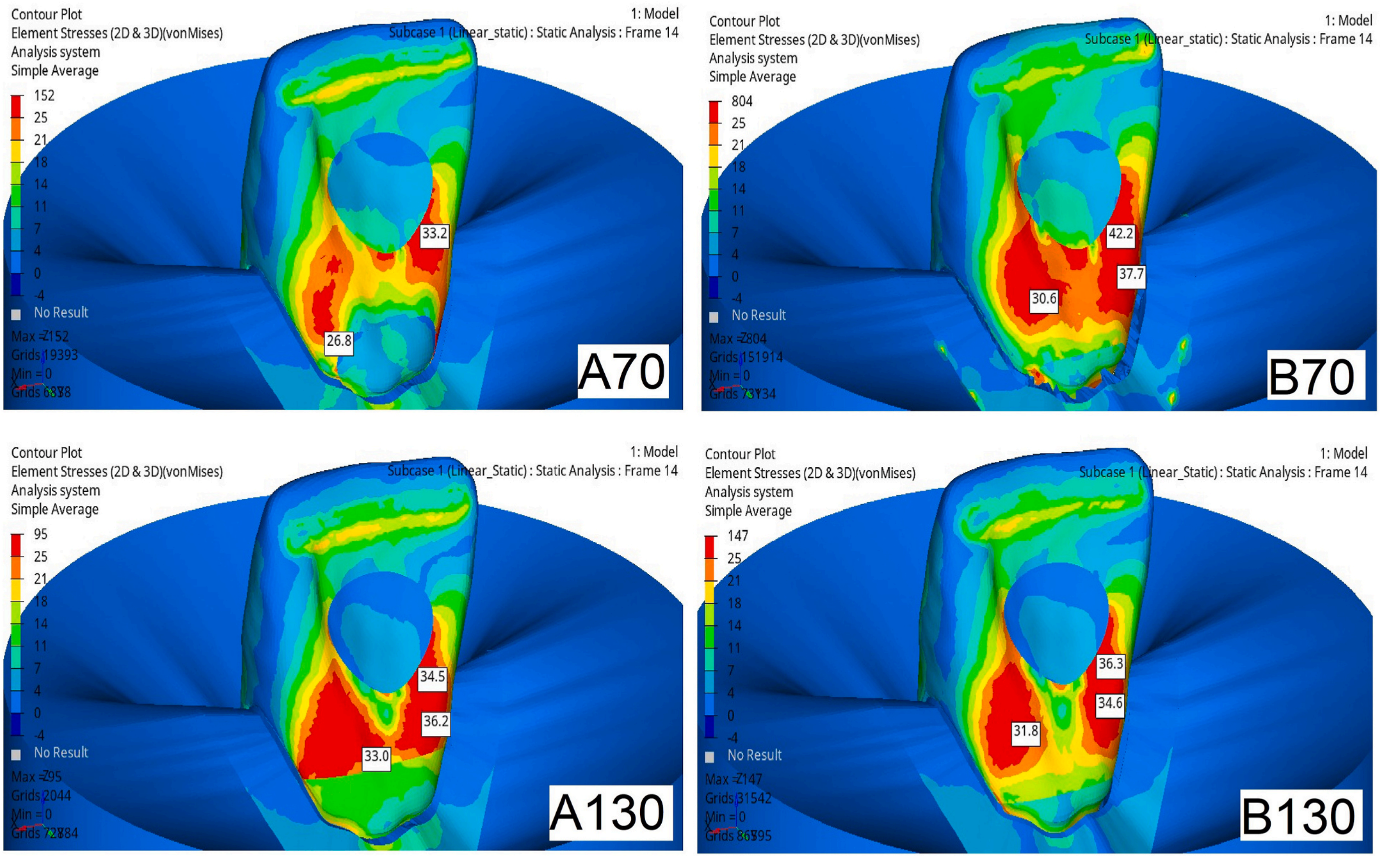

Fig. 3. Von Mises stress in whole tooth filled with Biodentine. A 70: Supracrestal Lesion with 70°circumferential spread filled with Biodentine, B 70: Subcrestal Lesion with 70°circumferetial spread filled with Biodentine.

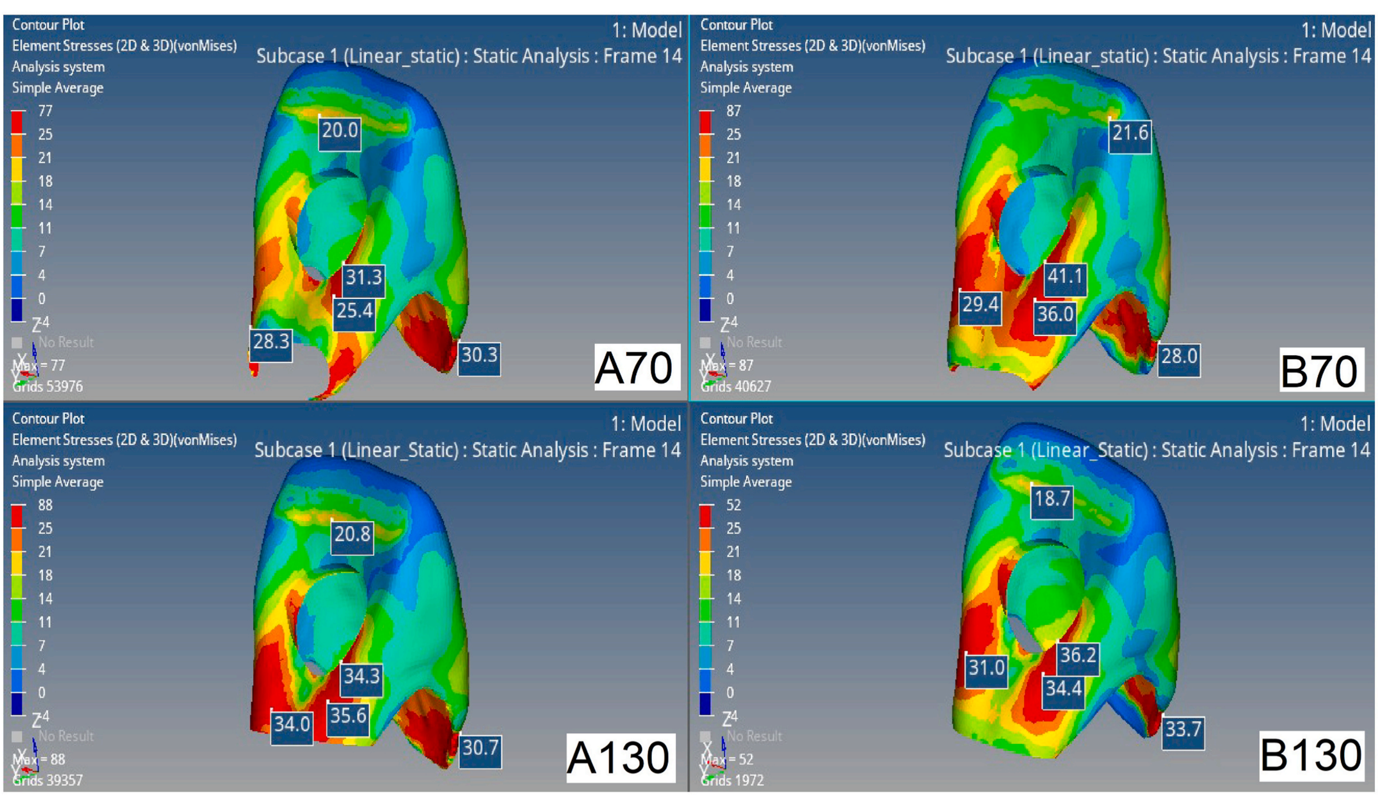

Fig. 4. Von Mises stresses in enamel filled with MTA. A 70: Supracrestal Lesion with 70°circumferential spread filled with MTA, B 70: Subcrestal Lesion with 70°circumferetial spread filled with MTA.

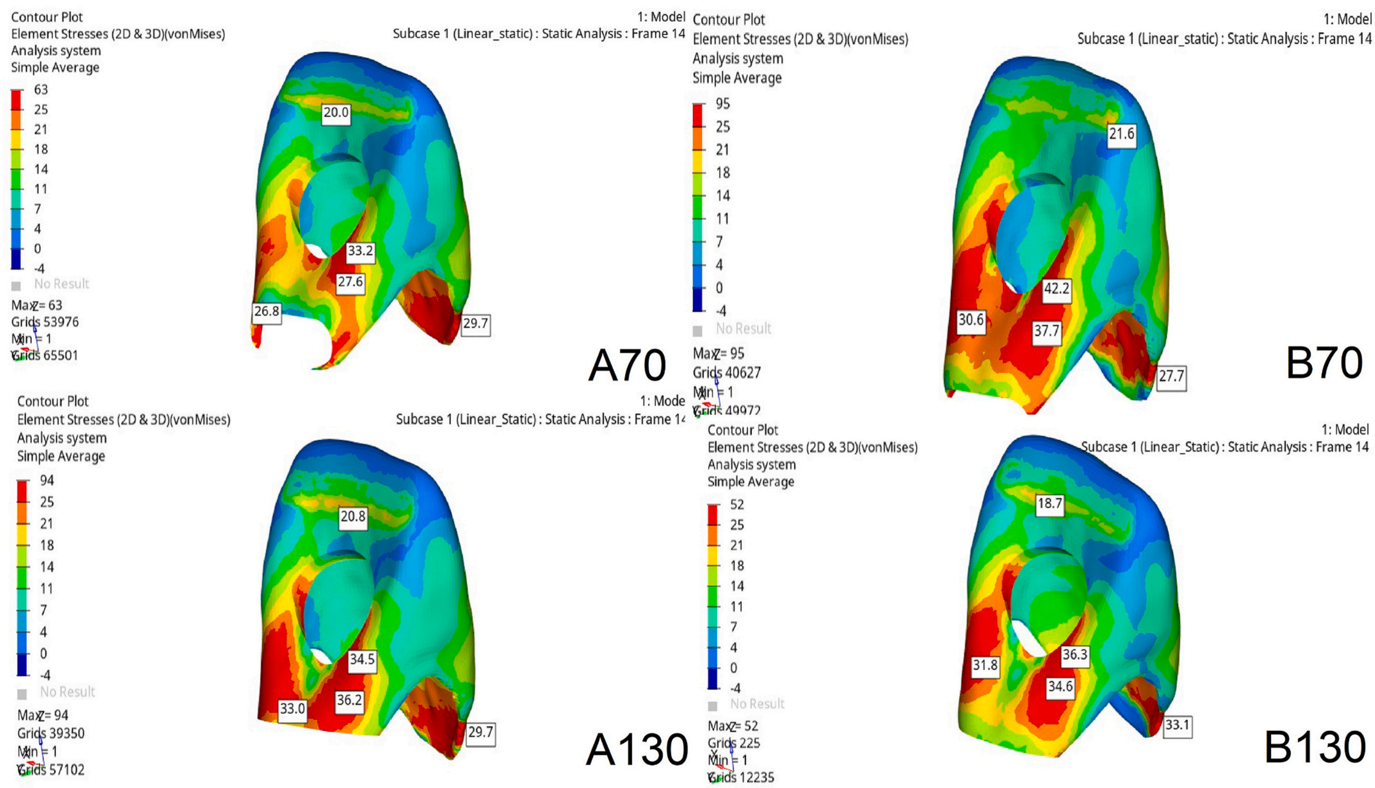

Fig. 5. Von Mise stresses in enamel filled with Biodentine. A 70: Supracrestal Lesion with 70°circumferetial spread filled with Biodentine, B 70: Subcrestal Lesion with 70°circumferetial spread filled with Biodentine.

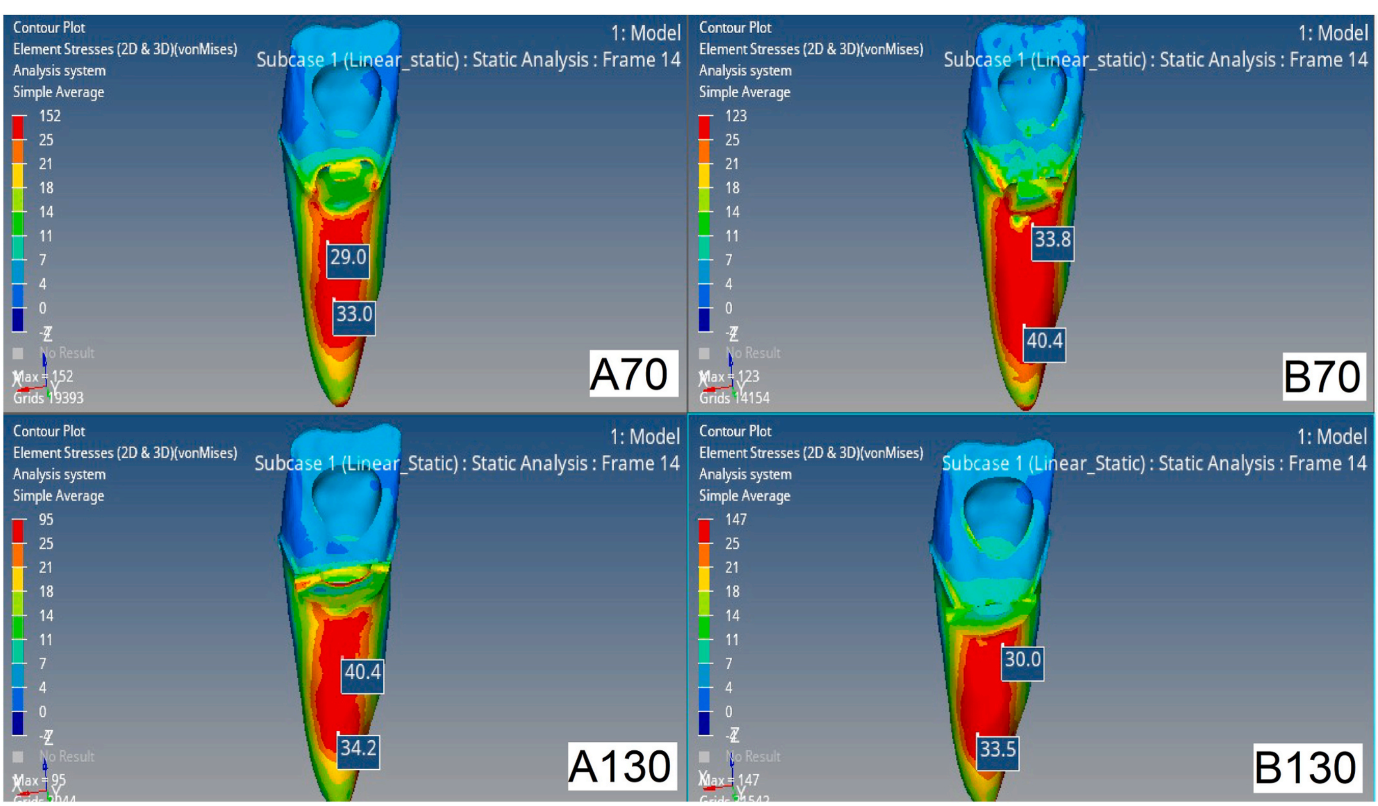

Fig. 6. Von Mises stresses in dentin filled with MTA. A 70: Supracrestal Lesion with 70°circumferential spread filled with MTA , B 70: Subcrestal Lesion with 70°circumferential spread filled with MTA.

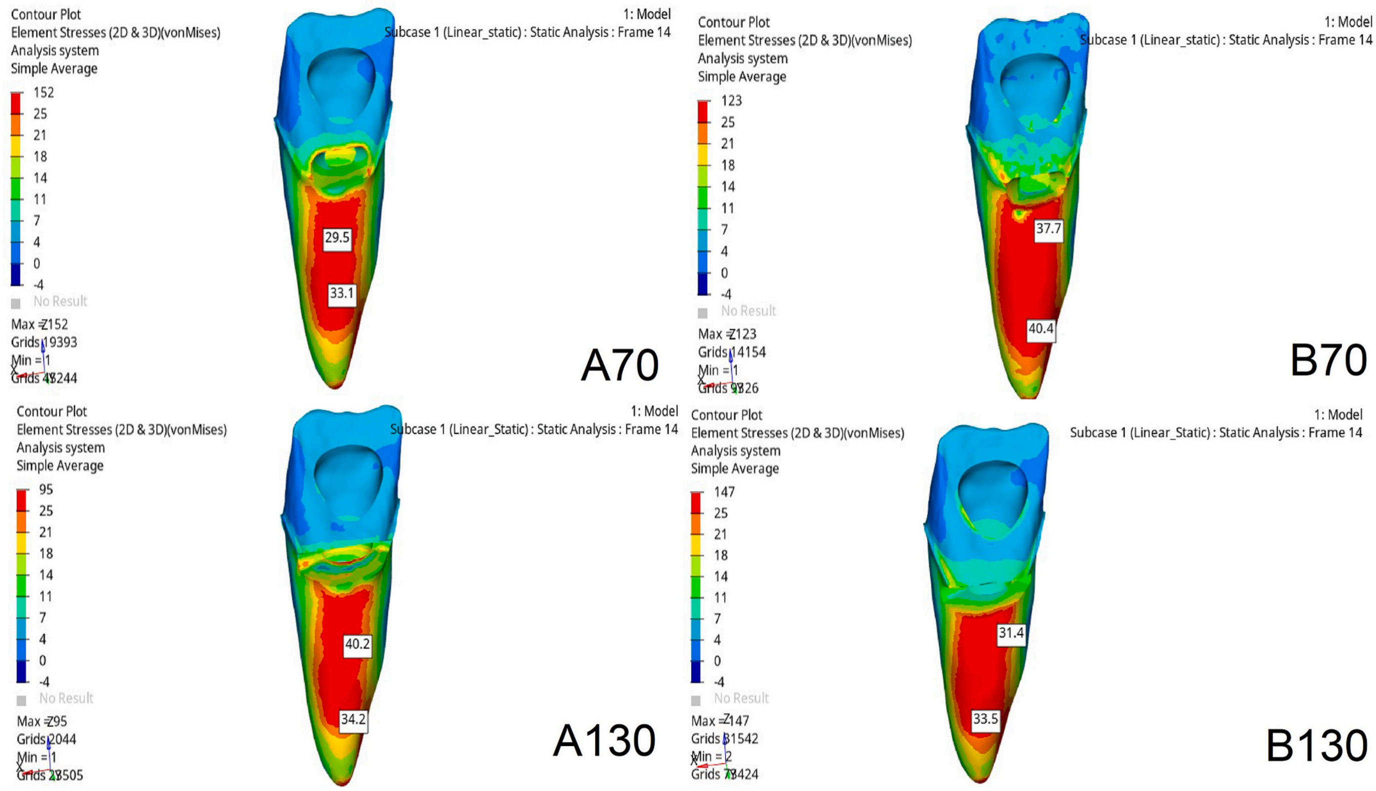

Fig. 7. Von Mises sresses in dentin filled with Biodentine. A 70: Supracrestal Lesion with 70°circumferential spread filled with Biodentine, B 70: Subcrestal Lesion with 70°circumferetial spread filled with Biodentine.

levels and with different circumferential spread restored with MTA or Biodentine.

It has been reported that maxillary central incisors are susceptible to external cervical resorption and thus these were used in the present study.[1] Stress concentrations are also the highest in the case of upper incisors. It could be attributed to the fact that the periodontal ligament area of central incisors is less and there is subsequent mobility under loading. This implies that incisors are more susceptible to the stresses generated by the loads applied during masticatory function.[13]

Dental materials and tissues can be analysed with the help of Finite Element Analysis by effectively simulating the real problems by performing numeric analysis which is practically impossible to perform in vivo. Resolutions of complex equations are made simpler by generating a mesh of the concerned structure's geometry. The mesh elements represent the discretization of the physical model, with the mechanical properties of the materials defining each element. The stresses are denoted by failure criteria, which turn the data into colour maps on a predetermined scale.[14]

Periodontal ligament of 0.2 mm and cortical bone of 2 mm and cancellous bone were modelled along with the dental hard tissues in all five central incisor models to simulate the oral conditions.[15] Root canal treatment was simulated by filling the canal space with Gutta Percha till the apical extent if the lesion and access cavity with composite resin. The resorptive cavities were restored with the test materials, MTA or Biodentine. The sealer layer was ignored in this study as it does not affect the stress distribution significantly due to its minimal quantity.[16]

Assumption was made that materials taken in the current study were isotropic, linearly elastic, and homogenous for simplification of the process. Though this might not reproduce the precise properties of many tissues and material, for example in this model, PDL was modelled as an elastic material while recent work has shown that the PDL is viscoelastic.[17]

Tensile stresses are seen in the cervical area of the palatal surface of an upper central incisor.[13] When oblique forces are applied to the palatal surfaces, tensile strains are created in the cervical area, generating flexion in the buccal direction. When these stresses exceed the tensile stresses of the enamel, dentin, or the restorative material, microfractures are bound to happen leading to restoration failure as flexion moment is highest is in this area.[13]

A conventional 100 N masticatory load was applied obliquely to the long axis at a 45° angle 2 mm lingual to incisal edge to simulate the centric contact.[18] This was done to standardize the forces in all of the groups to achieve a better comparison of the strengthening effect of materials.[19]

The results revealed that the stress distribution pattern and values were not influenced by the location and shape of the lesion. This could be attributed to the fact that elastic moduli of the restorative materials and dentin are similar, allowing a pseudo uniform transmission of the stresses across the dentin and restoration. The tensile stresses on the restoration interfaces were also similar.[20] It has been reported that lesions that are U-shaped with rounded borders have fewer stress concentrations when compared to V-shaped lesions. This might be the reason for reduced stress concentrations in our study as the lesions were U-shaped with rounded borders.[21] Composite resin and dentin have a similar modulus of elasticity, implying that the load so applied is distributed thereby reducing stress concentrations. Thus, restoring the access cavity with composite resin might also have favoured the results.[16]

The maximum stresses observed in all the models were very similar to each other as well as those of the natural tooth under load. This could be attributed to the fact that the restorative materials including the composite resin used to restore the access cavity have a high modulus of elasticity which makes the destruction less prominent. It has been proposed that from a mechanical point of view it can be said that placing a restorative material with a high modulus of elasticity is a good approach.[22]

Maximum stress observed after repair with MTA or Biodentine was quite similar, possibly due to similar structure and composition of MTA and Biodentine.[19] Modulus of elasticity of MTA and Biodentine is similar to that of dentin, thus behaving as a dentin structure. This helps keep the stress within the structure and share the stress with the dentin. The fracture risk is reduced with more homogenous stress. MTA has been demonstrated to increase the fracture strength of roots when used as a root canal filler material. Restoration of teeth filled with an adhesive material having same elastic modulus as dentin can save the remaining tooth structure and enhance its biomechanical properties by forming a monoblock.[8,11] A study by Eram et al.[22] reported that MTA decreases stresses at the cervical area and comparable results were seen in this study, although the difference was very slight. On the contrary, Aslan et al.[8] and Oksuger et al.[24] reported that the lowest stress concentrations were seen in simulated perforation models repaired with biodentine which was attributed to its higher modulus of elasticity which was similar to the denin substate.

MTA and Biodentine have an excellent sealing ability with low solubility after setting, providing a long-term seal. pH above 12 is observed at the time of setting due to the release of hydroxyl ions during their setting reaction. They possess antibacterial effects during setting and biocompatibility and bioactivity after setting.[19] Although Biodentine serves as an ideal replacement material for dentin, stress reduction in MTA restoration was more than that of Biodentine in our study. Even though our study showed higher fracture resistance for MTA, Biodentine is preferred over MTA due to several benefits like shorter setting time and better handling properties and consistency. Results of the current study were evaluated by von Mises equivalent stress that specifies the location of the maximum stressed areas. This serves as a sign of possible damage and is predictive of fatigue failure.[8]

Although, Finite element models help in determining the processes involved when loading teeth, they do not fully represent the clinical situation. In clinical scenarios, fractures usually occur due to dynamic loads and it is difficult to mimic these forces experimentally Another limitation was that the materials were assumed to be isotropic, homogeneous, and linearly elastic. As the biologic tissues are anisotropic and heterogeneous, therefore this virtual simulation did not reproduce the heterogeneity of the actual clinical condition.[23] Also, the Finite element analysis does not take into account oral environmental factors such as microleakage and microbial contamination and is purely a biomechanical analysis. Therefore, a direct clinical correlation becomes difficult as treatment outcome depends on multiple factors.

5. CONCLUSION

Within the limitations of the present research, it could be inferred that Finite element analysis offers valuable insights into the biomechanical responses of teeth affected by ECR lesions when restored with MTA and Biodentine. Both materials demonstrate comparable stress distribution patterns, effectively reinforcing the teeth against mechanical forces. Clinicians can confidently employ either MTA or Biodentine in addressing ECR, given their favorable biomechanical characteristics and clinical efficacy. However, further research is warranted to corroborate these results and refine treatment approaches for ECR.

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