

RESEARCH ARTICLE

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Stress Distribution in Fiber Post-Restored First Premolar Teeth with Periapical Lesions: A Finite Element Study

Fiber Post ile Restore Edilmiş Periapikal Lezyonlu Birinci Premolar Dişlerde Gerilme Dağılımının Sonlu Elemanlar Analizi ile İncelenmesi

ABSTRACT

Objectives

This study aimed to evaluate, using three-dimensional (3D) finite element analysis (FEA), the stress distribution within endodontically treated (RCT), periapical lesioned mandibular premolar teeth restored with fiber posts and metal-supported porcelain crowns under masticatory forces.

Material and Methods

Two FEA models representing different clinical scenarios were developed: a healthy mandibular premolar tooth (Model 1) and an RCT premolar tooth with a periapical lesion, restored with a fiber post and a metal-supported porcelain crown (Model 2). A static load of 300 N was applied to the occlusal surface at a 45° angle to the longitudinal axis of the tooth. Maximum equivalent stresses on dental tissues, post material, surrounding bone structures, and the periapical lesion were calculated and visualized according to the Von Mises criterion.

Results

Functional loading concentrated stresses predominantly at the buccal cervical region in both models. However, the fiber post model exhibited relatively higher stress values and greater deformation compared to the intact tooth, particularly at the cervical area and post-dentin interface.

Conclusion

It has been determined that the use of fibre posts in the restoration of teeth with periapical lesions leads to a concentration of stress distribution in the cervical region and at the post-dentine interface. Therefore, the resulting biomechanical load transfer mechanisms should be evaluated through an analytical and systematic clinical assessment.

Key Words

Fiber post, Metal-supported porcelain, Periapical lesion, Finite element analysis, Biomechanics

ÖZ

Amaç

Bu çalışmanın amacı, kök kanal tedavili (KKT), periapikal lezyonlu ve fiber post ile restore edilerek metal destekli porselen kron ile restore edilmiş mandibular premolar dişte, çiğneme kuvvetleri altında oluşan stres dağılımının üç boyutlu sonlu elemanlar analizi (SEA) yöntemiyle değerlendirilmesidir.

Gereç ve Yöntemler

Çalışmada iki farklı senaryoyu temsil eden SEA modelleri oluşturulmuştur: sağlıklı mandibular premolar diş (Model 1) ve periapikal lezyonlu, kanal tedavili, fiber post ve metal destekli porselen kron ile restore edilmiş premolar diş (Model 2). Modellerin oklüzal yüzeyine, dişin uzun aksıyla 45° açı yapacak şekilde 300 N değerinde statik yük uygulanmıştır. Diş dokuları, post materyali, çevre kemik yapıları ve periapikal lezyon üzerindeki maksimum eşdeğer gerilmeler Von Mises kriterine göre hesaplanmış ve simülasyon çıktıları hazırlanmıştır.

Bulgular

Fonksiyonel yükleme altında her iki modelde de gerilmeler ağırlıklı olarak bukkal servikal bölgede yoğunlaşmıştır. Ancak, fiber post uygulanan modelde, özellikle servikal bölgede ve post-dentin ara yüzünde, sağlam dişe kıyasla göreceli olarak daha yüksek gerilme ve daha fazla deformasyon değerleri gözlenmiştir.

Sonuç

Periapikal lezyonlu dişlerin restorasyonunda fiber post kullanımının, gerilme dağılımını servikal bölgede ve post-dentin ara yüzünde yoğunlaştırdığı belirlenmiştir. Bu nedenle, ortaya çıkan biyomekanik yük aktarım mekanizmalarının analitik ve sistematik bir klinik değerlendirme ile incelenmesi gereklidir.

Anahtar Sözcükler

Fiber post, Metal destekli porselen, Periapikal lezyon, Sonlu elemanlar analizi, Biyomekanik

INTRODUCTION

Pulpal destruction resulting from dental caries or trauma frequently necessitates endodontic intervention (1). The long-term success of root canal treated teeth depends not only on a successful endodontic protocol but also on the selection of an appropriate coronal restoration that preserves the tooth's biomechanical integrity (2,3). Especially in teeth with extensive tissue loss and the presence of periapical lesions, the behaviour of restorative materials under masticatory forces is of critical importance (4). This situation is a significant factor directly affecting the functional integrity and longevity of the tooth.

Periapical lesions are a common consequence of endodontic pathologies, causing destruction in the surrounding bone tissue and altering the mechanical relationship between the tooth and its supporting structures (1,5). These lesions, by reducing bone support in the apical region of the tooth, can adversely affect the distribution of masticatory forces and decrease the tooth's fracture resistance. Post-and-core systems, frequently used in the restoration of these teeth, are applied to increase the retention of the coronal restoration and support the remaining dental tissues (6,7). Fiber posts, with an elastic modulus close to that of dentin (approximately 18.6 GPa), ensure a more homogeneous distribution of stress along the root, thereby reducing the risk of vertical root fractures (8-12). This biomechanical advantage makes fiber posts a preferred option in the restoration of root canal treated teeth.

The difficulty of performing biomechanical studies *in vivo* in a clinical setting has led researchers toward numerical analysis methods. Finite Element Analysis (FEA) is a powerful engineering tool that allows for the investigation of the mechanical behaviour of biological structures with complex geometries under standardized and controllable conditions (13-17). Although many studies in the literature have examined healthy or root canal treatment (RCT) teeth using FEA (18-20), studies (2,19,21) investigating the effect of periapical lesions on fiber-post restorations are limited. This gap highlights the need for such studies to better understand the biomechanical performance of fiber posts in the restoration of teeth with periapical lesions.

This study aims to examine the stress distributions occurring under functional loads in an abutment tooth with a periapical lesion restored with a fiber post using the FEA method, evaluating the impact of the lesion and the post material on biomechanical performance. The findings obtained are intended to provide valuable information to clinicians regarding material selection and treatment planning in the restoration of teeth with periapical lesions.

MATERIAL and METHODS

A three-dimensional (3D) finite element analysis was performed to investigate the stress distribution in mandibular premolar teeth functioning as abutments for fixed prosthetic restorations, with particular focus on the effect of a periapical lesion on the biomechanical behaviour of the restored tooth.

All solid models used in the analyses were generated by reconstructing the dental components separately in SolidWorks 2021 (SolidWorks Corp., Massachusetts, USA) three-dimensional parametric modeling software. The modeling process was based on real-size 3D human tooth models published by the School of Dentistry, University of Dundee. A reverse engineering approach was adopted to reconstruct the anatomical structures of the tooth and its subcomponents. This method allows accurate reproduction of the geometry of biological structures using available digital models, reference images, and computer-aided design data. The reconstructed mandibular premolar tooth served as the abutment for prosthetic restorations. RCT and subsequent post restoration were simulated using the 3D CAD model. The structural analyses were conducted using Structural Module of the ANSYS Workbench (ANSYS Inc., Canonsburg, PA, USA) finite element software.

During model construction and analysis, several assumptions were applied. The geometry of the restored mandibular premolar and prosthetic components was simplified to eliminate unnecessary surface irregularities while maintaining clinically relevant anatomical features. The cementum layer was considered as a separate structure from dentin. Perfect bonding was assumed between all components, and no interfacial gaps were considered. Residual stresses caused by root canal treatment procedures were not included in the simulations. In addition, all materials were assumed to be homogeneous, isotropic, and linearly elastic, which is a common and acceptable assumption in FEA studies of dental structures.

The dentin component was modelled together with the post, core, crown, periodontal ligament (PDL), and gutta-percha, ensuring full anatomical conformity with the natural tooth structure and surrounding tissues. Post space preparation was simulated in accordance with established clinical protocols, with an apical seal preserved to maintain endodontic integrity. The PDL was represented based on its physiological characteristics to reflect realistic biomechanical behaviour.

The model comprised cortical bone, trabecular bone, PDL, dentin, gutta-percha, post, post cement, core, crown cement, and crown, all constructed to replicate anatomical morphology and tissue interfaces accurately. A glass fibre post system (ParaPost Fiber White, Coltène/Whaledent, Mahwah, USA) was incorporated, and its geometry was designed to be consistent with clinically applied post configurations. The ferrule design and remaining root struc-

ture were defined in accordance with restorative principles, preserving the anatomical continuity of dentin.

A dual-cure resin cement (Ivoclar Vivadent, Schaan, Liechtenstein) was employed as the luting agent, with interfacial layers modelled to reflect clinically realistic bonding conditions. The core build-up was simulated using a resin composite material, and the finish line geometry was designed to be consistent with prosthodontic preparation standards at the gingival level. The final restoration consisted of a metal-supported porcelain crown, resulting in a premolar tooth model that is fully aligned with anatomical and clinical realities.

After the periapical lesion-free reference model was established, clinical scenarios were created to evaluate the mechanical behaviour of the system under loading conditions. The periapical lesion was modelled as a spherical solid separation located at the root apex.

Two models were analysed in this present study (Fig. 1):

Model 1. Healthy mandibular premolar tooth without RCT or post restoration (control model).

Model 2. Root canal treated mandibular premolar restored with a fiber post and metal-supported porcelain crown in the presence of a periapical lesion.

Mesh Generation

The finite element mesh was generated using the ANSYS Workbench meshing functions. The models were discretized using tetrahedral elements. Relatively smaller element sizes were applied to critical regions such as the root surface, post-dentin interface, and periapical lesion area to capture stress gradients more accurately. Mesh refinement was performed in areas where higher stress concentrations were expected, improving the numerical accuracy of the analysis. Model 1 and Model 2 consist of approximately 1 391 674 and 1 488 380 finite elements, and 2 042 012 and 2 200 073 nodes, respectively. A skewness value of 0.232 indicates excellent mesh quality.

Material Properties

Material properties were assigned to each component of the model based on values reported in previous studies. The elastic modulus, Poisson's ratio and density values of the materials were defined within the FEA software. All materials were assumed to behave as homogeneous, isotropic, and linearly elastic (Tab. 1) (22).

Boundary Conditions and Loading

Boundary conditions were defined to simulate physiological support conditions. The inferior surfaces of the cortical and trabecular bone blocks were fixed in all degrees of freedom to prevent rigid body motion, while the remaining external surfaces were left unconstrained. A static oc-

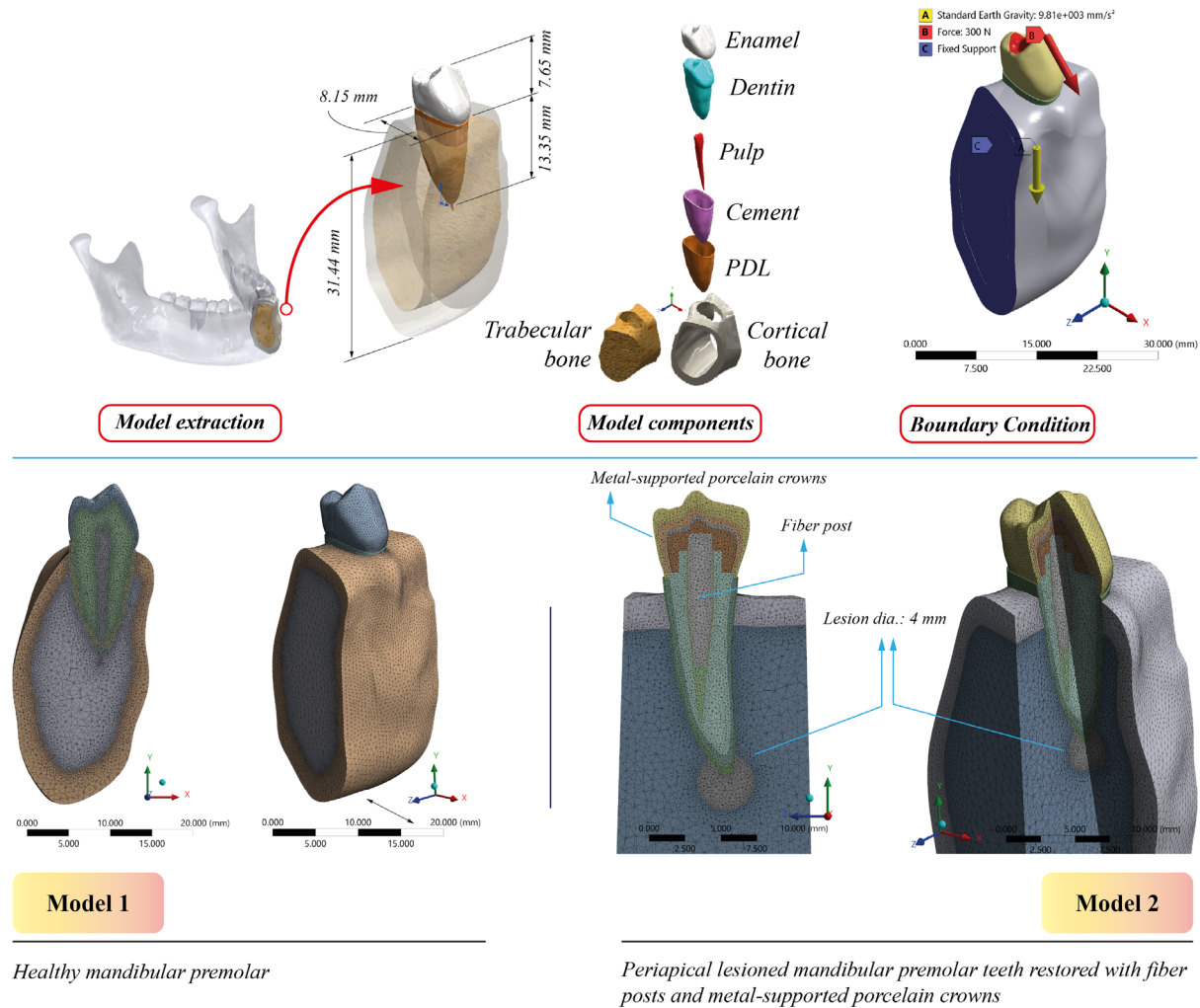


Figure 1. Finite element model development and configuration.

Table 1. Material properties assigned in the FEA.

Model Component	Modulus of Elasticity (MPa)	Poisson's Ratio (-)	Density (kg m ⁻³)
Enamel	82700	0.33	2800
Dentin	18600	0.31	2200
Cortical bone	14000	0.323	1400
Cancellous bone	1370	0.38	850
Periodontal Ligament (PDL)	68.90	0.45	1100
Cement	10000	0.30	2030
Lesion tissue	0.69	0.45	370
Glass fibre post (Coltène/Whaledent Inc)	20000	0.30	2500
Composite Core	12400	0.30	2400
Crown (porcelain)	68900	0.28	2300
Gutta-percha	0.69	0.45	370
Adhesive resin cement	7600	0.30	2000
Metal Framework (Substructure)	200000	0.30	7800

clusal load of 300 N was applied to the occlusal surface of the mandibular premolar at an angle of 45° relative to the long axis of the tooth. The load was applied to the buccal cusp incline, representing functional masticatory forces acting on premolar teeth during occlusion.

Contact Definitions and Stress Evaluation

In order to perform the analyses, contact relationships between the model components were defined within the simulation environment. All interfaces were assumed to be perfectly bonded, representing ideal adhesion between restorative materials and dental tissues. The stress distributions generated under loading conditions were evaluated using the Von Mises stress criterion, which is widely used to assess the mechanical behaviour and potential failure of dental structures and restorative materials.

RESULTS

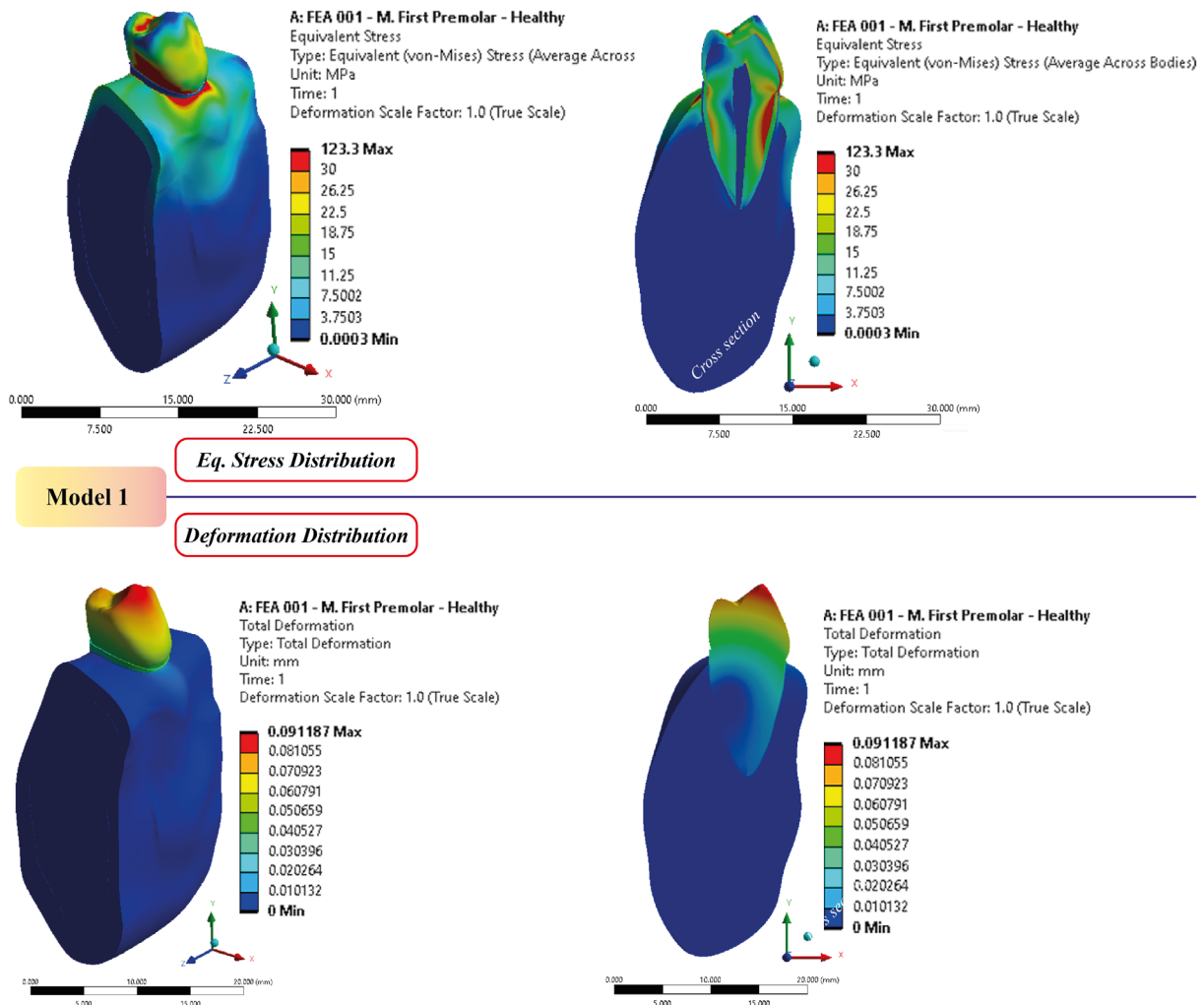
The maximum equivalent (von Mises) stress values and total deformation results obtained from the FEA are summarised in Table 2. Model 2 exhibited a slightly higher global deformation (0.098 mm) compared to Model 1 (0.091 mm), indicating a slight increase in overall structural deformation, reflecting a more compliant mechanical response. Similarly, the global maximum equivalent stress increased from 123.300 MPa in Model 1 to 133.870 MPa in Model 2.

Under occlusal loading, stress concentrations were predominantly localised in the buccal and palatal cervical regions in both models. These regions correspond to areas of direct force transmission and geometrical discontinuity, where stress accumulation is biomechanically anticipated (4,18). In Model 1, the maximum stress within the tooth structure reached 82.4 MPa, whereas in Model 2 this value slightly decreased to 78.6 MPa, suggesting a redistribution effect associated with the fibre post system. Figure 2 presents the stress distributions in Model 1 (healthy tooth), along with the corresponding total deformation values.

Table 2. Summary of maximum deformation and von Mises stress values for all components in both models.

Component / Region	Model 1 (Healthy Tooth)	Model 2 (Periapical Lesion + Fiber Post)	Stress Location
Global Deformation (mm)	0.091	0.098	Whole model
Global Equivalent Stress (MPa)	123.300	133.870	Whole model
Tooth Structure (Dentin/Enamel) (MPa)	82.4	78.6	Buccal cervical / cervical third
Cortical Bone (MPa)	24.5*	21.2*	Cervico-buccal region
Trabecular Bone (MPa)	4.8*	3.5*	Periapical / middle third
Crown (Porcelain / Enamel) (MPa)	123.300	109.200	Occlusal surface
Substructure (Ni-Cr) (MPa)	–	133.870	Crown framework
Post Material (MPa)	–	45.3	Cervical region
Periapical Lesion (MPa)	–	0.061	Apical region

* Global values represent the maximum von Mises stress and total deformation obtained from the entire finite element model, whereas the values marked with (*) correspond to region-specific stress concentrations within individual anatomical components.



In Model 2, the incorporation of the fibre post facilitated a more gradual transfer of stresses from the root canal space to the surrounding dentinal tissues. The post itself exhibited a maximum stress of 45.3 MPa, primarily concentrated in the cervical region, indicating its active participation in load sharing. These findings are consistent with previous

studies reporting that fibre posts, due to their elastic modulus being closer to dentine, promote a more homogeneous stress distribution and reduce stress concentrations within the root structure (8-12). The stress and deformation distributions of Model 2 are illustrated in Figure 3.

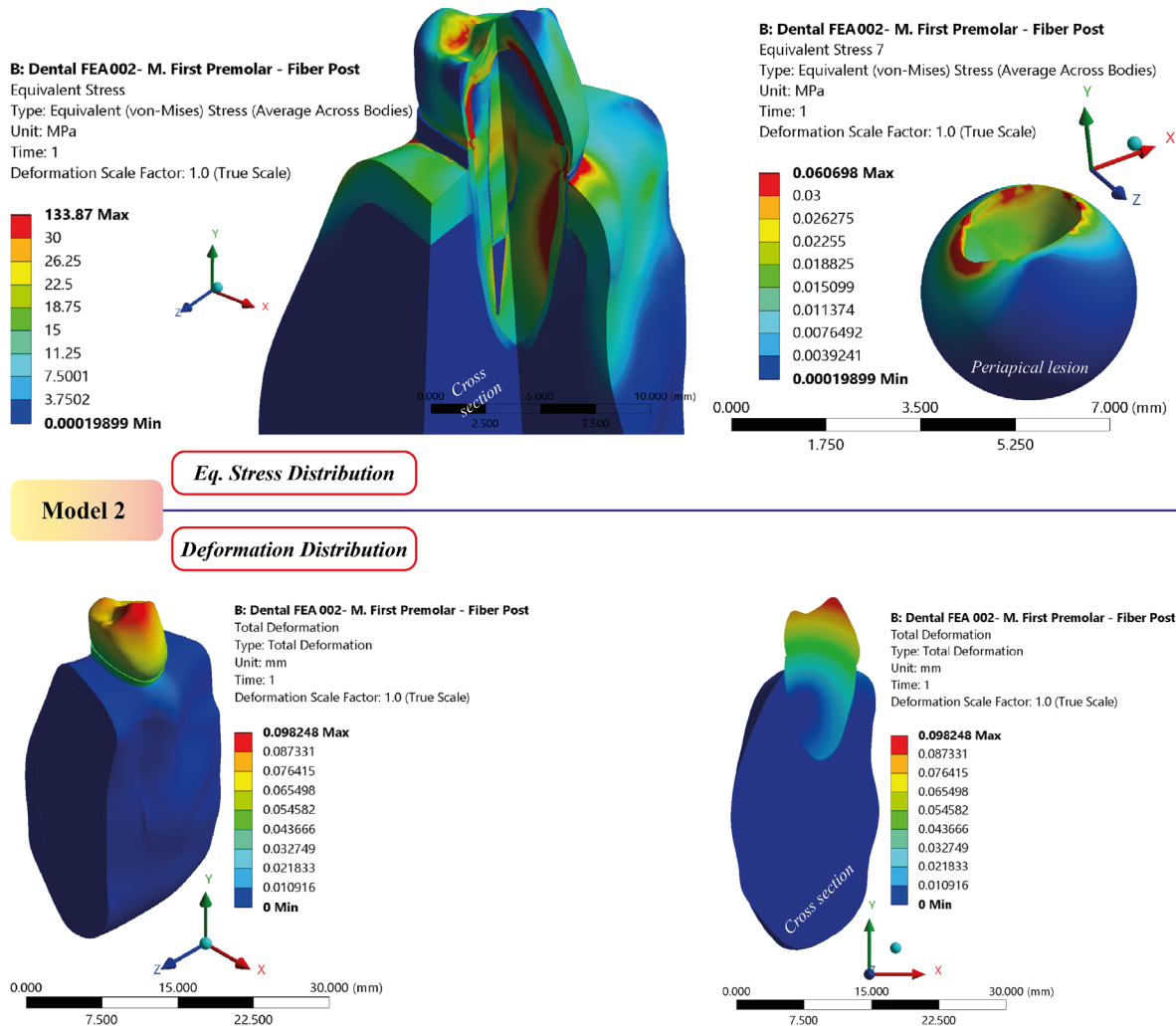


Figure 3. Stress and deformation distributions in Model 2 (periapical lesion restored with fibre post).

With respect to supporting structures, cortical bone consistently exhibited higher stress values than trabecular bone in both models. In Model 1, cortical bone stress reached 24.5 MPa, decreasing to 21.2 MPa in Model 2, whereas trabecular bone stresses were substantially lower (4.8 MPa and 3.5 MPa, respectively). This observation is consistent with the higher stiffness and load-bearing capacity of cortical bone.

Interestingly, despite the higher global stress in Model 2, localised stresses within both cortical and trabecular bone were reduced compared to Model 1. This behaviour may be attributed to the presence of the periapical lesion, which exhibited negligible stress (0.061 MPa) and functioned as a compliant region with a low elastic modulus. Consequently, part of the applied load was attenuated before being transmitted to the surrounding bone tissue, supporting the concept of a stress-damping effect (1,5,21).

However, this mechanical behaviour should be interpreted cautiously in a clinical context due to the biological implications of periapical tissue loss.

DISCUSSION

This study investigated the biomechanical behaviour of a premolar tooth with a periapical lesion restored using a fibre post system through FEA. The findings demonstrate that fibre posts contribute to a more favourable stress distribution, while the presence of a lesion alters the overall mechanical response of the system (1, 26).

The results confirm that fibre posts reduce stress concentrations within the dentinal structure by redistributing loads more uniformly. In the present study, the reduction in dentinal stress from 82.4 MPa in Model 1 to 78.6 MPa in Model 2, together with the observed stress transfer to the post (45.3 MPa), indicates effective load sharing be-

tween restorative components and tooth structure. This supports existing literature stating that fibre posts, due to their elastic modulus being similar to dentine, minimise stress concentrations and reduce the likelihood of catastrophic vertical root fractures (8-12). Furthermore, their mechanical compatibility enables a more physiological transmission of occlusal forces compared to rigid metallic posts (14).

The slightly higher global stress and deformation observed in Model 2 suggest increased structural flexibility of the restored system. This behaviour is consistent with the mechanical compatibility of fibre-reinforced materials, which allow energy dissipation rather than stress concentration. Therefore, from a biomechanical perspective, fiber posts may enhance the resilience of root canal treated teeth, particularly in structurally compromised conditions (20).

The presence of a periapical lesion, although clinically undesirable, demonstrated a notable influence on stress distribution. The reduction of cortical bone stress from 24.5 MPa to 21.2 MPa and trabecular bone stress from 4.8 MPa to 3.5 MPa suggests that the lesion acts as a compliant region, partially absorbing occlusal loads (1,5). This finding aligns with previous studies indicating that low-stiffness regions can modify load transfer pathways within biological systems (21). Similar observations have been reported by Jang *et al.* (18) who demonstrated that apical structural alterations influence stress distribution patterns, and by Karaoğlu *et al.* (21) who highlighted the role of lesion size in shifting stress concentrations within surrounding bone.

However, this apparent mechanical advantage should not be misinterpreted clinically. The loss of apical support may compromise overall tooth stability, increase mobility, and alter PDL loading conditions (22,23). Thus, while stress reduction in bone may be observed numerically, the biological and functional consequences of periapical lesions remain detrimental.

The consistently higher stress levels observed in cortical bone compared to trabecular bone are in agreement with their respective mechanical properties. Cortical bone, due to its higher elastic modulus, bears a greater proportion of occlusal loads. The reduced bone stress observed in Model 2 may also be partially attributed to the restorative system, particularly the metal-supported porcelain crown, which appears to contribute to load redistribution within the system (23,24). This suggests that restorative components may function as auxiliary load-bearing structures.

Several limitations of this study should be acknowledged. The assumption of isotropic, homogeneous, and linear elastic material behaviour does not fully represent the anisotropic and heterogeneous nature of dental and bone tissues. Additionally, loading conditions were static, and dynamic, cyclic, and fatigue effects were not considered. The analysis was limited to a single premolar model, and

variations in tooth morphology, occlusal conditions, and patient-specific factors were not included. It should be noted that Model 2 incorporates multiple simultaneous variables (periapical lesion, fibre post, core, and crown), and therefore the individual contribution of each factor cannot be isolated within the present study design. Future studies should incorporate more advanced material models, dynamic loading scenarios, and patient-specific geometries to enhance the clinical relevance of the findings.

CONCLUSION

Within the limitations of this study, the following conclusions were reached:

1. Fiber post material distributes stresses within the root homogeneously and at levels that do not damage dentin tissue, even in teeth with apical lesions (8-12). This indicates that fiber posts are biomechanically compatible with dentin tissue and reduce the risk of vertical root fracture.
2. Maximum stresses are concentrated in the buccal cervical region of the tooth in both models; this area is clinically one of the most at-risk for fracture (4,18). This finding highlights the need for restorations to manage stress concentrations in this region.
3. The periapical lesion acts as a stress damper under masticatory forces, altering the amount of load transmitted to the surrounding bone tissue (1,5,21). The presence of the lesion modifies the stress distribution in bone tissue, potentially reducing stress in some areas while increasing it in others.
4. The combination of fiber post and metal-supported porcelain in the restoration of root canal treated and lesioned teeth demonstrates biomechanically acceptable performance (2-4,6,7,24,25). This combination offers an effective solution for preserving the functional integrity of the tooth and ensuring its long-term success.
5. However, the long-term clinical performance and potential complications associated with metal-supported porcelain restorations should be considered despite their favourable load distribution characteristics (23).

Supplementary

An example study using FEA in dentistry can be accessed at the following link: <https://pmc.ncbi.nlm.nih.gov/articles/PMC12351966/>

Abbreviations

3D: Three Dimensional, FEA: Finite Element Analysis, RCT: Root Canal Treatment, PDL: Periodontal Ligament

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Authors' Contributions

Concept: Ö.K., H.K.Ç.; Supervision: Ö.K.; Resources: A.T.K., E.Ş.; Materials: A.T.K., E.Ş.; Data Collection and/or Processing: Ö.K.; Analysis and/ or Interpretation: H.K.Ç.; Literature Search: A.T.K.; Writing Manuscript: Ö.K., E.Ş., H.K.Ç.; Critical Review: Ö.K., H.K.Ç.

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Data Availability

Data is available from the corresponding author upon request.

Ethics Approval

Not required.

Conflicts of Interest

The authors declare no conflicts of interest.

AI Declaration

No AI tools were used.

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1. Nair PN. On the causes of persistent apical periodontitis: a review. *Int Endod J.* 2006; 39: 249-81. doi: [10.1111/j.1365-2591.2006.01099.x](https://doi.org/10.1111/j.1365-2591.2006.01099.x)
2. Kırmalı Ö, Akar MB, Çelik HK, *et al.* Stress distribution in endodontically treated and differently restored teeth with periapical lesions: a 3D finite element analysis study. *BMC Oral Health.* 2025; 14; 25: 1326. doi: [10.1186/s12903-025-06682-z](https://doi.org/10.1186/s12903-025-06682-z)
3. Belli S, Eraslan O, Hakki SS, *et al.* Effect of post restoration on stresses in premolars with endodontic-periodontal lesion: an FEA study. *J Adhes Sci Technol.* 2017; 31: 1-11. doi: [10.1080/01694243.2016.1222742](https://doi.org/10.1080/01694243.2016.1222742)
4. Chen S, Hong X, Ye Z, *et al.* The effect of root canal treatment and post-crown restorations on stress distribution in teeth with periapical periodontitis: a finite element analysis. *BMC Oral Health.* 2023; 6; 23: 973. doi: [10.1186/s12903-023-03612-9](https://doi.org/10.1186/s12903-023-03612-9)
5. Lin LM, Ricucci D, Lin J, *et al.* Nonsurgical root canal therapy of large cyst-like inflammatory periapical lesions and inflammatory apical cysts. *J Endod.* 2009; 35: 607-15. doi: [10.1016/j.joen.2009.02.012](https://doi.org/10.1016/j.joen.2009.02.012)
6. Zarow M, Vadini M, Chojnacka-Brozek A, *et al.* Effect of fiber posts on stress distribution of endodontically treated upper premolars: a finite element analysis. *Nanomaterials.* 2020; 10: 1708. doi: [10.3390/nano10091708](https://doi.org/10.3390/nano10091708)
7. Yang B, Wang B, Du L, *et al.* The finite element analysis of the impact of ferrule height and post-core materials on stress distribution in incisors. *Int Dent J.* 2025; 75: 100918. doi: [10.1016/j.identj.2025.100918](https://doi.org/10.1016/j.identj.2025.100918)
8. Madfa AA. Effect of dental glass fiber posts on root stresses and fracture behavior of endodontically treated maxillary central incisors: a finite element analysis study. *Cureus.* 2023; 6: 15: E43056. doi: [10.7759/cureus.43056](https://doi.org/10.7759/cureus.43056)
9. Feiming L, Ying S, Tongtong H, *et al.* Finite element analysis of endodontically treated premolars without ferrule restored with one-piece glass fiber post and core in combination with different inner shoulder retention form systems. *J Mech Behav Biomed Mater.* 2023; 143: 105912. doi: [10.1016/j.jmbbm.2023.105912](https://doi.org/10.1016/j.jmbbm.2023.105912)
10. Aggarwal S, Garg V. Finite element analysis of stress concentration in three popular brands of fiber posts systems used for maxillary central incisor teeth. *J Conserv Dent.* 2011; 14: 293-6. doi: [10.4103/0972-0707.85819](https://doi.org/10.4103/0972-0707.85819)
11. Akman S, Akman M, Eskitascioglu G, *et al.* The use of endodontically treated teeth restored with fiber posts as abutments for fixed partial dentures. *Clin Oral Investig.* 2012; 16: 1485-91. doi: [10.1007/s00784-011-0635-7](https://doi.org/10.1007/s00784-011-0635-7)
12. Furuya Y, Huang SH, Takeda Y, *et al.* Fracture strength and stress distributions of pulpless premolars restored with fiber posts. *Dent Mater J.* 2014; 33: 852-8. doi: [10.4012/dmj.2014-113](https://doi.org/10.4012/dmj.2014-113)
13. da Rocha DM, Tribst JPM, Ausiello P, *et al.* Effect of the restorative technique on load-bearing capacity, cusp deflection, and stress distribution of endodontically-treated premolars with MOD restoration. *Restor Dent Endod.* 2019; 7: 44: E33. doi: [10.5395/rde.2019.44.e33](https://doi.org/10.5395/rde.2019.44.e33)
14. Badami V, Ketineni H, Sabiha P, *et al.* Comparative evaluation of different post materials on stress distribution in endodontically treated teeth using finite element analysis: a systematic review. *Cureus.* 2022; 29: E29543. doi: [10.7759/cureus.29753](https://doi.org/10.7759/cureus.29753)
15. Unsal GC, Yusufoglu SI. Finite element analysis of endocrown and post-and-core abutments for removable partial dentures with different framework materials. *Int J Prosthodont.* 2023; 36: 203-15. doi: [10.11607/ijp.7269](https://doi.org/10.11607/ijp.7269)
16. Ausiello P, Gloria A, Maietta S, *et al.* Stress distributions for hybrid composite endodontic post designs with and without a ferrule: FEA study. *Polymers (Basel).* 2020; 12: 1836. doi: [10.3390/polym12081836](https://doi.org/10.3390/polym12081836)
17. Verri FR, Okumura MHT, Lemos CAA, *et al.* Three-dimensional finite element analysis of glass fiber and cast metal posts with different alloys for reconstruction of teeth without ferrule. *J Med Eng Technol.* 2017; 41: 644-51. doi: [10.1080/03091902.2017.1385655](https://doi.org/10.1080/03091902.2017.1385655)
18. Jang Y, Hong HT, Roh BD, *et al.* Influence of apical root resection on the biomechanical response of a single-rooted tooth: a 3-dimensional finite element analysis. *J Endod.* 2014; 40: 1489-93. doi: [10.1016/j.joen.2014.03.006](https://doi.org/10.1016/j.joen.2014.03.006)

19. Koç S, Kirmalı Ö, Çelik HK. Evaluation of stress patterns in teeth with endodontic treatment and periapical lesions as abutments for fixed prosthesis: a finite element analysis study. *BMC Oral Health*. 2025; 24: 130. doi: [10.1186/s12903-025-05501-9](https://doi.org/10.1186/s12903-025-05501-9)
20. Ausiello P, Gloria A, Maietta S, et al. Stress distributions for hybrid composite endodontic post designs with and without a ferrule: FEA study. *Polym (Basel)*. 2020; 16: 1836. doi: [10.3390/polym12081836](https://doi.org/10.3390/polym12081836)
21. Karaoglu I, Er K, Kustarci A, et al. How periapical lesion size affects stress distribution in endodontically treated maxillary incisors: a finite element analysis. *Comput Methods Biomech Biomed Engin*. 2026, *in press*. doi:[10.1080/10255842.2025.2609654](https://doi.org/10.1080/10255842.2025.2609654)
22. Celik HK, Koc S, Kustarci A, et al. A literature review on the linear elastic material properties assigned in finite element analyses in dental research. *Mater Today Commun*. 2022; 30: 103087. doi: [10.1016/j.mtcomm.2021.103087](https://doi.org/10.1016/j.mtcomm.2021.103087)
23. Pjetursson BE, Valente NA, Stradling M, et al. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. *Clin Oral Implants Res*. 2018; 29: 199-214. doi: [10.1111/clr.13306](https://doi.org/10.1111/clr.13306)
24. Pirani C, Camilleri J. Effectiveness of root canal filling materials and techniques for treatment of apical periodontitis: a systematic review. *Int Endod J*. 2023; 56: 436-54. doi: [10.1111/iej.13787](https://doi.org/10.1111/iej.13787)
25. Kirmali O, Zeynali A, Akar T, et al. Biomechanical behavior of endodontically treated abutment teeth with periapical lesions: a 3D finite element analysis. *Eur J Dent*. 2026, *in press*. doi:[10.1055/s-0045-1814774](https://doi.org/10.1055/s-0045-1814774)
26. Aslan T, Esim E, Ustun Y. Finite element evaluation of dentin stress changes following different endodontic surgical approaches. *Odontology*. 2024; 112: 798-810. doi:[10.1007/s10266-023-00882-1](https://doi.org/10.1007/s10266-023-00882-1)