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Stress distribution in endodontically treated and differently restored teeth with periapical lesions: a 3D FEA study

Ömer Kırmalı[1], M. Barış Akar[2], H. Kürşat Çelik[3] and Kürşat Er[4*]

Abstract

Background The mechanical performance of post materials used in endodontically treated teeth under occlusal loading is a critical determinant of long-term restorative success but remains insufficiently understood. In this study, stress distributions within teeth with periapical lesions restored using different post materials, as well as their surrounding tissues under occlusal load, were investigated using advanced engineering simulation technique.

Materials and methods The finite element method based engineering analysis technique was employed, and five incisor tooth models representing healthy teeth and teeth restored with different post materials were used: (Model 1) healthy tooth; (Model 2) tooth with root canal treatment (RCT), periapical lesion, and metal-supported porcelain crown; (Model 3) tooth with a periapical lesion, fibre post, and metal-supported porcelain crown; (Model 4) tooth with a periapical lesion, cast metal post, and metal-supported porcelain crown; and (Model 5) tooth with a periapical lesion, zirconia post, and metal-supported porcelain crown. A static load of 100 N was applied to the palatal surface at an angle of 135° to the longitudinal axis. Equivalent stress distribution was analysed using the von Mises criterion, with particular attention to stress magnitudes within the tooth structure, post material, surrounding bone, and periapical region.

Results Models 1, 2, and 3 exhibited stress concentrations primarily in the cervical and middle thirds of the root, with the highest stresses localised in the cervical region. The healthy model (Model 1) demonstrated the highest maximum equivalent stress (80.687 MPa), followed by Model 3 (76.681 MPa) and Model 2 (54.188 MPa). The presence of periapical lesions reduced overall stress levels due to the localised softening of the trabecular bone. Models 4 and 5 showed higher stress concentrations within the post materials (70.49 MPa and 69.27 MPa, respectively). In all models with lesions, stress within the lesion area remained consistently low (0.0164–0.0191 MPa).

Conclusions Fibre-reinforced posts demonstrate superior biomechanical performance in endodontically treated teeth with periapical lesions, providing a stress distribution pattern that more closely resembles that of healthy teeth compared to rigid post materials.

Keywords Periapical lesion, Finite elemental analysis, Fiber post, Cast metal post, Zirconia post

*Correspondence:
Kürşat Er
qursater@hotmail.com
[1]Department of Prosthodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey
[2]Private Practice, Akar Dental Clinic, Antalya, Turkey
[3]Department of Agr. Machinery and Technology Engineering, Akdeniz University, Antalya, Turkey
[4]Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey

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Introduction

Tooth decay remains one of the most widespread oral health conditions worldwide, exerting a substantial impact on patients' quality of life by impairing masticatory efficiency and compromising facial aesthetics. When left untreated, carious lesions can progress beyond the enamel and dentine to involve the dental pulp. Such progression may lead to irreversible pulpitis or pulpal necrosis, conditions that commonly necessitate endodontic intervention to preserve the affected tooth. Effective clinical management of severely compromised tooth structure necessitates early diagnosis and the implementation of appropriate restorative or endodontic interventions. Such timely treatment is essential to halt further structural degradation and to preserve the functional integrity of the oral cavity [1]. If the damage to the pulp tissue is reversible, vital pulp therapy methods are employed; however, if the damage is irreversible, root canal treatment (RCT) is indicated [2]. In cases where RCT is required, caries have affected the pulp by causing loss of material in the tooth and often triggered the formation of periapical lesions [3]. While most periapical lesions heal following appropriate endodontic treatment, long-term follow-up-sometimes extending up to four years-may be required to ensure complete resolution [4]. The long-term success of conservative treatment in non-vital teeth depends on multiple factors, including the preservation of remaining dentine, the quality and durability of the bond between restorative materials and the enamel–dentine complex, and the properties of the restorative material itself, in addition to the effective execution of RCT [2].

Since many of the teeth with periapical lesions that had received RCT show excessive loss of tissues in the coronal tooth structure, dental post-applications are needed to provide coronal restoration retention and root resistance [5, 6]. There are many dental post systems available on the market and scientifically investigated in literature, such as prefabricated posts, metal (stainless steel and titanium), and non-metal (carbon fiber, glass fiber, zirconia) posts [7]. Fibre posts, which exhibit an elastic modulus comparable to that of dentine (18600 MPa) [8] are widely utilised due to their favourable aesthetic properties [9]. The biomechanical response of teeth to masticatory forces differs between anterior and posterior regions due to anatomical and functional variations. These complex interactions, particularly in restorations involving materials with different elastic moduli, are difficult to reproduce accurately through in vitro tests. Therefore, advanced numerical method-based engineering analysis methods are employed to analyse internal stress distributions. Finite Element Analysis (FEA) is a widely used technique that enables the simulation of stress and deformation in dental structures under standardized and controlled conditions. It allows for the assessment of specific variables while minimizing human-related variability. Previous studies have successfully employed FEA to investigate the mechanical behaviour of restorative materials and preparation designs in endodontically treated teeth [10–15]. Therefore, FEA was employed as the primary analysis method in this study due to its robustness in simulating complex biomechanical behaviours.

Numerous FEA studies in the literature have investigated the stress distribution patterns associated with various post systems in RCT teeth, recognising that differences in the elastic modulus of post materials play a critical role in determining how stresses are transmitted and dissipated under functional loading. Chuang et al. [16] demonstrated that stress tends to concentrate in the cervical region of the crown, whereas Badami et al. [17] found that, in all FEA models involving fibre posts, stress was primarily localised in the palatal third of the root. Shetty et al. [18] further observed that stress distribution within fibre post models was comparatively homogeneous, while models with zirconia posts exhibited higher stress concentrations within the post itself. Similarly, Ausiello et al. [12] reported that the use of a hybrid composite post alone can optimise stress distribution by efficiently transferring occlusal loads from the coronal portion towards the apical region. Additionally, another study [19] indicated that fibre posts can reduce overall stress levels by approximately 21%, while cast metal posts can achieve a reduction of around 25% compared to an intact tooth, highlighting the biomechanical advantage of appropriate post selection.

One of the most common complications in post applications is root fractures. After endodontic treatment, the post-applied teeth should be restored to function in the mouth for a long time, to support the remaining dental tissues and to protect the root canal system [20]. Beyond their restorative function, the preservation of root integrity remains a critical clinical objective in post-endodontic treatments, as inadequate protocols may predispose teeth to horizontal root fractures [21, 22]. At present, metal-ceramic (metal-supported porcelain) restorations are the most commonly employed option for the rehabilitation of such teeth, accounting for approximately 80% of clinical cases [23].

Previous studies have shown that the occurrence of a secondary periapical lesion is common in teeth that have undergone RCT during the follow-up period [24, 25]. To date, insufficient number of studies in the literature have reported on the stress distribution within the tooth and surrounding bone tissue when different post materials are subjected to occlusal loading in teeth with periapical lesions. On the other hand, it was reported that the survival rate of teeth restored with fiber posts and crowns after endodontic treatment was six times higher than that

of teeth restored without crowns and showed a survival rate of 85.1% after ten years of function [26]. Furthermore, in another study evaluating teeth restored with zirconia, cast metal, and fibre posts, each subsequently restored using the same crown material following endodontic treatment, it was observed that teeth restored with fibre posts demonstrated the lowest survival rate [27].

The primary objective of this study is to evaluate, using three-dimensional (3D) FEA, the stress distribution and deformation behaviour of endodontically treated teeth with periapical lesions restored with different dental post materials. Particular emphasis is placed on assessing the mechanical response of both the periapical lesion region and the surrounding tooth structure. Since the choice of post material can influence the survival rate of restored teeth under occlusal loading, it is crucial to consider the biomechanical impact of materials with varying mechanical properties on both the dental tissues and supporting structures. Clinical success in RCT is critically dependent on preserving the tooth's biomechanical integrity and promoting optimal periapical healing. Therefore, a clear understanding of the stress distribution and mechanical interactions within endodontically treated teeth is essential. The findings of this study may offer valuable guidance for future long-term clinical follow-ups and in vitro studies focusing on the restoration of structurally compromised teeth with different post systems. In line with this aim, the following two null hypotheses were tested: (1) the type of post material used in teeth with periapical lesions does not significantly influence stress distribution patterns; and (2) there is no significant variation in the stress response of cortical and trabecular bone under functional loading across the different finite element model configurations.

Materials and methods

Identification of structural components and development of the master model

The foundational 3D solid model of the maxillary left central incisor utilised in this study was sourced from publicly accessible computer-aided design (CAD) resources developed within the framework of educational initiatives led by the School of Dentistry at the University of Dundee, Scotland. These resources, available via the Sketchfab digital platform (https://sketchfab.com/DundeeDental/models), were originally designed to support the creation of anatomically accurate 3D visualisations for dental education and training purposes. The use of this validated digital model ensures a high level of anatomical fidelity, making it particularly well-suited for biomechanical simulations and FEA involving endodontically treated or restored teeth [20, 23–28]. Different post materials and metal-supported porcelain restorations, following endodontic treatment, were processed using SolidWorks 2021 3D parametric CAD software (SolidWorks Corp., Massachusetts, USA). These models were subsequently imported into ANSYS Workbench 2020. R1 (ANSYS Inc., Canonsburg, PA, USA), which served as the primary platform for conducting structural analyses.

In the FEA scenarios run for this study, the following assumptions were applied to ensure consistency and computational feasibility:

(a) All components within the modelled assemblies were presumed to be perfectly bonded, implying the absence of interfacial gaps or micromovements between adjacent structures;
(b) The cross-sectional surfaces of the cancellous and cortical bones were fully constrained to inhibit any translational or rotational displacements, thereby replicating a fixed boundary condition;
(c) Normal pre-stresses that might arise as a result of RCT procedures were omitted from the simulations, under the assumption that their contribution to overall stress distribution would be negligible;
(d) The geometric model of the maxillary central incisor, restored with a post–core system and a metal–ceramic crown, was idealised to simplify the analysis without compromising clinical relevance; and
(e) All materials used in the tooth model were defined as homogeneous, isotropic, and linearly elastic, in accordance with widely accepted conventions in dental biomechanics modelling.

In this study, a two-phase FEA was conducted to assess the biomechanical behaviour of a maxillary central incisor under distinct clinical conditions. In the first phase, a healthy, lesion-free tooth model was developed to establish a baseline reference for evaluating the mechanical consequences of endodontic treatment, selection of post material, and subsequent prosthetic restoration. This initial analysis served as a benchmark for comparative assessment. In the second phase, a separate model was constructed to replicate a tooth with a periapical lesion that had undergone RCT and was restored with a metal-ceramic crown. This allowed for a detailed investigation of how different post systems influence the mechanical performance of structurally compromised teeth. All anatomical and restorative structures were carefully reconstructed to replicate clinically relevant conditions as faithfully as possible (Fig. 1). This modelling approach aimed to yield clinically meaningful insights into load-bearing capacity and stress distribution patterns associated with various restorative scenarios in both healthy and pathologically affected teeth, thereby addressing the study's objective.

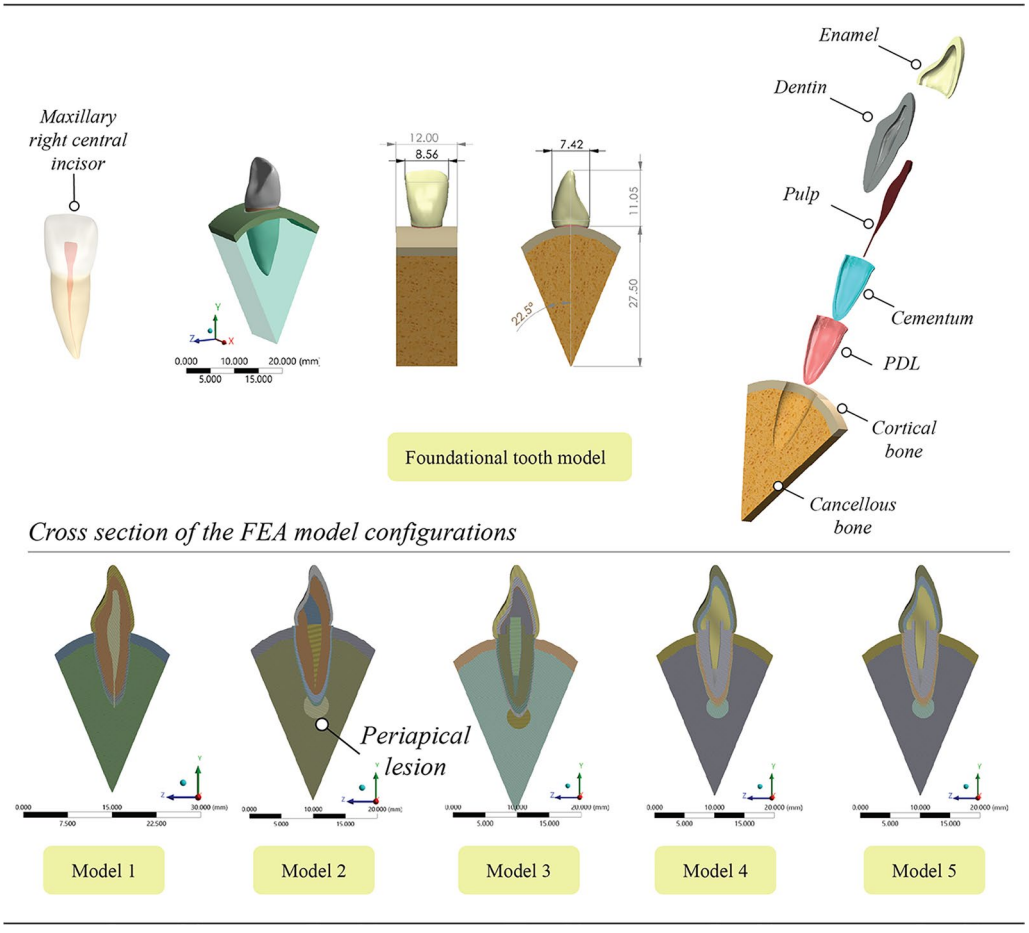


Fig. 1 FEA model configurations (Model 1: healthy tooth model; Model 2: tooth with RCT, periapical lesion, metal-supported porcelain crown; Model 3: tooth with the periapical lesion, fiber post, metal-supported porcelain crown; Model 4: tooth with a periapical lesion, cast metal post, metal supported porcelain crown; Model 5: tooth with a periapical lesion, zirconia post, metal supported porcelain crown)

During model development, anatomical and restorative reference dimensions were adopted based on established clinical and biomechanical parameters to ensure analytical accuracy and practical relevance. To examine the effect of post material, three distinct post systems were integrated into Models 3, 4, and 5. Specifically, Model 3 included a glass fibre post (ParaPost® Fiber White, Coltène/Whaledent, Mahwah, USA); Model 4 incorporated a custom-cast post fabricated from a nickel-chromium (Ni-Cr) alloy; and Model 5 featured a zirconia post. For all configurations, the cementation interface between the core and the crown was simulated using a dual-cure resin cement (Ivoclar Vivadent, Schaan, Liechtenstein). In Model 3, the core build-up was modelled using composite resin (ParaPost® Fiber White, Coltène/Whaledent), whereas in Models 4 and 5, the core was designed as an integral monoblock continuous with the post material [29–31]. These anatomical and restorative parameters provided the basis for configuring the FEA models. Recognising the inherent complexity and variation in dental surface morphology, the computational models were refined to approximate these reference dimensions as precisely as possible. Remaining anatomical structures were adjusted accordingly to maintain geometric accuracy, structural realism, and anatomical fidelity within the simulation framework.

Material model and mesh structure

The material properties, representing the physical characteristics of each anatomical component in the FEA models, were defined by importing the corresponding data into the simulation environment. Specifically, the elastic modulus and Poisson's ratio were used to characterise the mechanical behaviour of each structure. For modelling the pulp tissue, property values were referenced from previous studies focusing on teeth with periapical lesions (Tables 1 and 2).

The mesh structures of the models were generated using the meshing functions of the FEA code. To ensure an accurate representation of the geometric features, particularly at the contact interfaces, relatively smaller element sizes were applied in these regions. This approach

Table 1 Material properties assigned in the FEA set up

Material properties (FEA definitions - Homogenous isotropic linear elastic material model)			
Material	**Modulus of Elasticity**	**Poisson's Ratio**	**Density**
	(MPa)	**(-)**	**(kg m^{-3})**
Enamel	84,100	0.33	2800
Dentin	18,600	0.31	2200
Cortical bone	14,000	0.323	1400
Cancellous bone	1370	0.38	850
Pulp	2.10	0.45	1000
PDL	68.90	0.45	1100
Cementum	8200	0.31	2030
Lesion tissue	0.69	0.45	370
Composite	12,400	0.3	2400
Crown (porcelain)	68,900	0.28	2300
Gutta-percha	0.69	0.45	370
Adhesive resin cement	7600	0.3	2000
Fiber Post	37,000	0.27	2500
Zirconia Post	200,000	0.31	5500
Ni-Cr Post	204,000	0.3	7600

aimed to maximise the overall quality of the mesh. The skewness mesh quality metric was employed for internal validation of the models, with an average skewness value of 0.234 indicating a high-quality finite element mesh (Fig. 2a).

Boundary conditions

To perform the analyses within the developed FEA models, all interfaces between individual components were defined as fully bonded, ensuring 100% contact without relative motion. To eliminate unwanted translations and rotations during simulation, the tooth structures were constrained at their lateral and superior surfaces. This boundary condition setup is consistent with methodologies reported in comparable studies [32]. A static load of 100 N was applied at an angle of 135° to the long axis of the maxillary central incisor in each model (Fig. 2a). However, in contrast to these studies, and to more accurately reflect clinical conditions, the force in our models was applied over a surface area rather than at a single point.

Results

When five distinct clinical scenarios were assessed across all models, it was observed that the application of an occlusal load (100 N at 135°) consistently resulted in stress concentrations within the cervical and middle thirds of the root. Specifically, stress accumulation was localised in the buccal cervical region of the tooth in Models 1, 2, and 3, whereas in Models 4 and 5, the highest stress levels were primarily concentrated within the post material itself (Fig. 2b). The region where the maximum stress occurred was in the buccal cervical region of the tooth for Model 1, Model 2, and Model 3, while it occurred in both labial and palatal regions of the post material in Model 4 and Model 5. In all models, a homogeneous decrease in the stresses in both the tooth and the cancellous bone was observed from the cervical to the apical region. When the maximum equivalent stress values were compared, the highest value was observed in Model 1 (80.68 MPa) and the lowest value in Model 2 (54.18 MPa). In all models, homogeneously decreasing and similar deformation distribution values were observed from the incisal 1/3 to the cervical area.

In all FEA models, the maximum equivalent stress observed in the cortical bone was consistently higher than that in the trabecular bone (Fig. 3). Among the models, Model 1 exhibited the highest equivalent stress in the cortical bone (70.11 MPa), whereas the maximum stress values in the remaining models were comparatively similar. Notably, the region of peak stress concentration was consistent across all models and was localised to the cortical bone adjacent to the cervico-buccal region of the tooth. In the trabecular bone, the maximum equivalent stress was recorded at the cervico-buccal level of the tooth in Model 1 (3.34 MPa) and Model 2 (3.68 MPa), whereas in Model 3 (4.04 MPa), Model 4 (4.83 MPa), and Model 5 (4.83 MPa), it was observed apically, extending towards the palatal region (Fig. 3a).

In the models with periapical lesions, the maximum equivalent stress values within the lesion were relatively low across Models 2 to 5, ranging from 0.016 to 0.019 MPa (Fig. 2b). The highest stress concentrations in the periapical lesion were consistently observed in the

Table 2 Numerical results of deformation and equivalent (von Mises) stress obtained from the FEA

FEA Output		**Components**	**FEA Model Configurations**				
			Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Maximum Deformation	(mm)	Global (Whole Model)	0.051	0.047	0.047	0.044	0.044
Maximum Equivalent Stress (von Mises)	(MPa)	Global (Whole Model)	80.687	54.188	76.681	70.495	69.273
		M. Cortical Bone	70.117	50.203	50.005	49.267	49.287
		M. Trabecular (Cancellous) Bone	3.340	3.688	4.040	4.838	4.838
		Crown (Porcelain/Enamel)	80.687	21.843	57.977	48.839	48,949
		Post	–	–	14.881	70.495	69.273
		Ni-Cr substructure	–	54.188	76.681	37.418	37.498
		Lesion	–	0.016	0.018	0.019	0.019

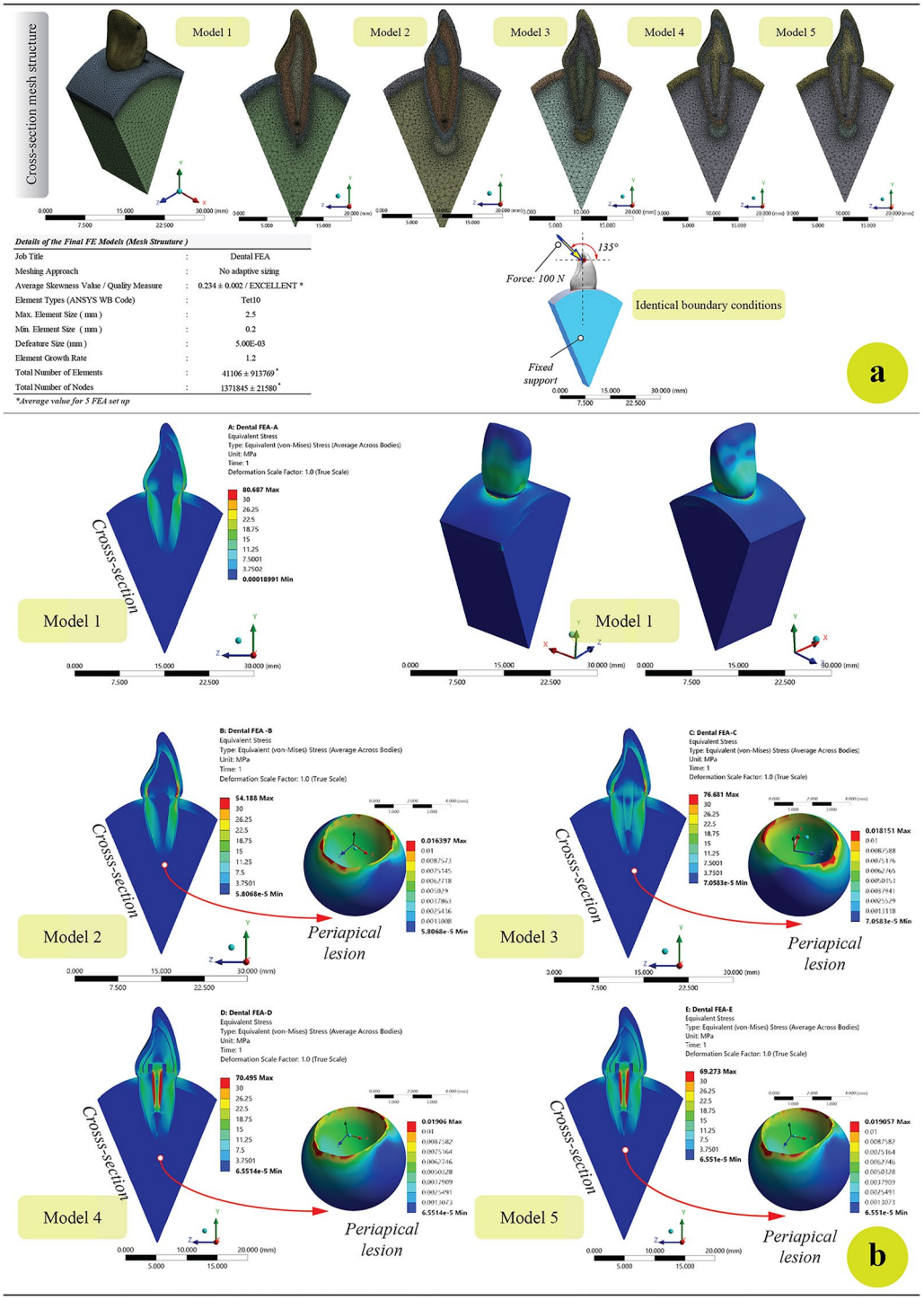


Fig. 2 **a** Mesh Structure characteristics and **b** Equivalent (von Mises) stress distribution across models and periapical lesions

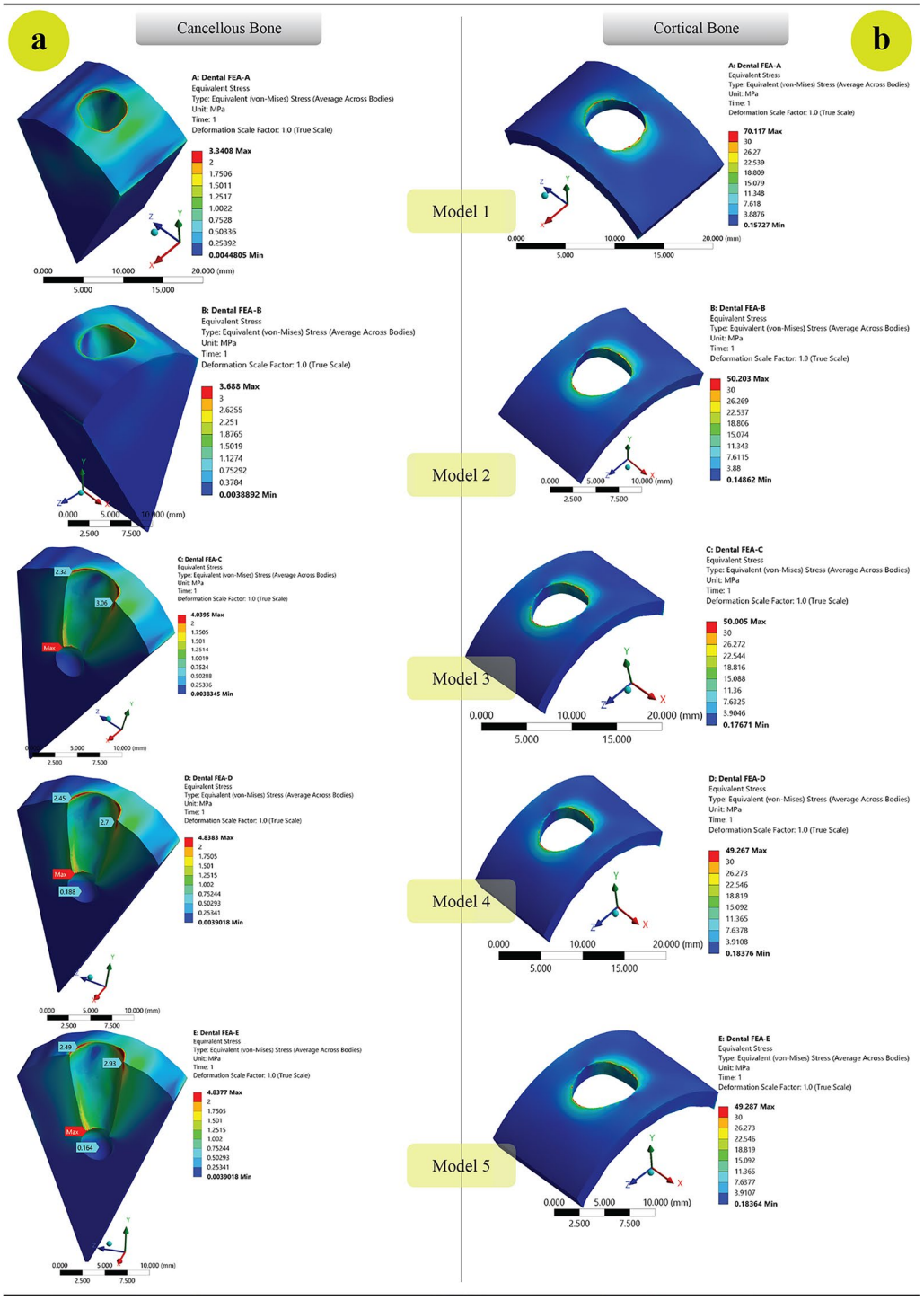


Fig. 3 Distribution of Equivalent (von Mises) Stress in Cancelleous (**a**) and Cortical Bone (**b**)

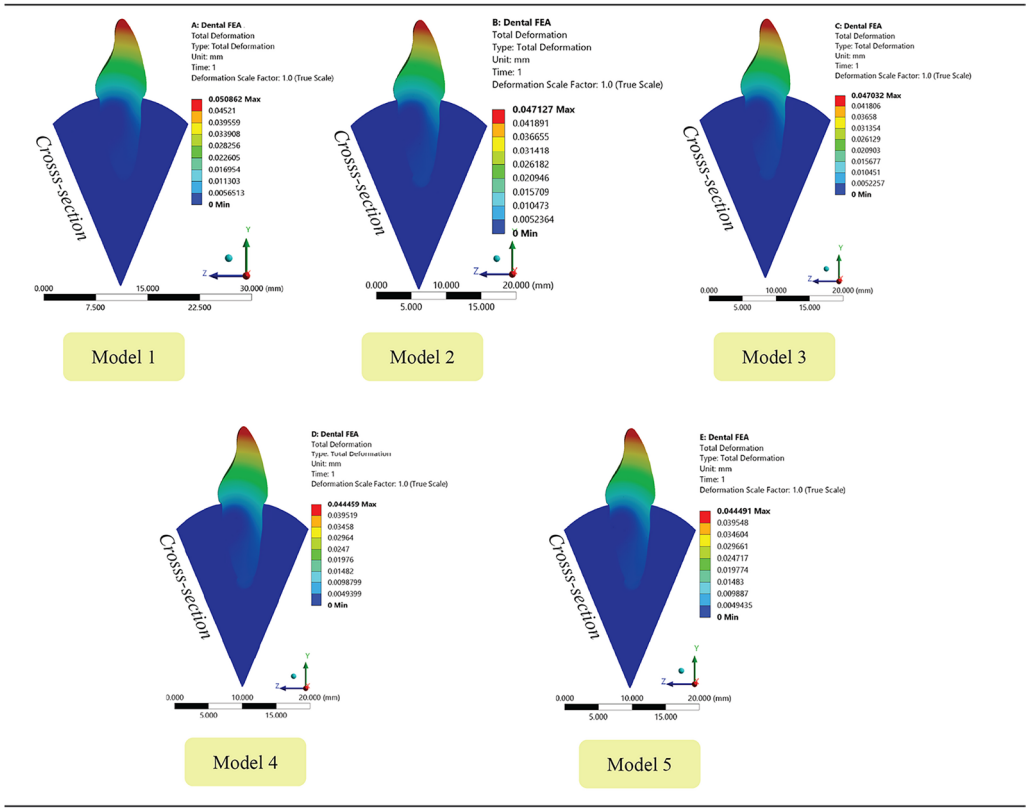


Fig. 4 FEA results illustrating deformation patterns

palatal region. The stress levels in the trabecular bone surrounding the periapical lesion remained low and similar in the models that included post restorations. Furthermore, the deformation values ranged from 0.0445 to 0.0508 mm, which are considered relatively minor and unlikely to exert any clinically significant adverse effects on the tooth during functional occlusal loading (Fig. 4).

Discussions

One notable advantage of employing the FEA method for assessing stress concentrations is its capacity to standardise and precisely control all experimental conditions [33]. In this study, every effort was made to replicate clinically relevant scenarios as accurately as possible; nonetheless, it must be acknowledged that the inherent complexity of the in vivo environment cannot be entirely reproduced. The results indicated that the application of different post materials in endodontically treated teeth with periapical lesions led to discernible variations in stress distribution within the cortical and trabecular bone, as well as across various structural components of the tooth under occlusal loading (based on the analysis of absolute stress values). Accordingly, both null hypotheses were rejected.

In cases where endodontic treatment is required, caries have caused loss of material in the tooth, affecting the pulp and often stimulates the formation of periapical lesions [2]. Since teeth with periapical lesions usually heal within the first year, it is recommended to follow for at least one year before using them as prosthetic abutments [34]. Teeth with RCT are subject to excessive loss of material due to caries, trauma or previous restorations, so a post is often needed to provide retention to the coronal restoration [6]. It is recommended the post-applied RCT teeth was crowned in order to protect and increase their biomechanical effects, and it has been shown that the correct selection of the restorative material to be applied will contribute to this situation [15]. It has been reported that coronal restoration of these teeth contributes to tooth prognosis and periapical healing [35]. However, to date, there is a lack of comprehensive studies in the literature that have systematically examined the stress distribution patterns associated with various post materials in endodontically treated teeth with periapical lesions, particularly with respect to their effects on the remaining tooth structure, the surrounding alveolar bone, and the lesion area itself.

The different elastic modulus of the different post materials to be used will affect the distribution of the stress that will occur against the force [16, 17]. In this study, it was observed that the stresses in the fiber post model (Model 3) were concentrated in the buccal and

palatal areas of the buccal region of the tooth and the cervical and middle third of the root. It was found that the stress values on the post were lower than cast metal and zirconia post models and the stresses decreased homogeneously towards the apical region. The results of this study demonstrate that fibre posts exhibit an elastic modulus comparable to that of natural dentine, which contributes to their favourable biomechanical behaviour. This property makes them a particularly suitable restorative choice for teeth with substantial structural loss. Moreover, these findings are consistent with those reported by Podili et al. [36], who highlighted the capacity of fibre posts to reduce the risk of root fracture.

In a comparative study of cast metal and fibre posts [33], stress concentrations were predominantly localised within the cast metal post, whereas a more uniform stress distribution was observed in the fibre post model. Specifically, examination of the regions surrounding the posts revealed homogeneously distributed low-stress zones in the fibre post model, in contrast to distinct areas of elevated stress in the buccal and palatal regions in the cast metal post model. In our study, comparison with the intact tooth model revealed that stress values decreased by approximately 5% in the fibre post model and by 12.63% in the cast metal post model. Furthermore, it was observed that, in the model incorporating a cast metal post and a periapical lesion (Model 4), stress concentrations were localised predominantly along the buccal and palatal surfaces of the post. Notably, although the post lengths differed from those used in our analysis, Santos-Filho et al. [33] reported comparable stress distribution patterns for both post materials, supporting the consistency of our findings. Similarly, our results align with those presented by Dejak and Młotkowski [19]. It is also well documented that, while metal posts provide greater fracture resistance in endodontically treated teeth, they are more likely to induce catastrophic fracture patterns when failure occurs [37].

The stress distribution in dentin was examined and it was reported that the highest stresses in all models were observed in the bucco-coronal third of the root [38]. The highest stresses were concentrated in the coronal and middle third of the buccal root, while in the zirconia post model with a periapical lesion (Model 5), the stress was concentrated on the post in this study. Despite the difference in elastic modulus and Poisson's ratio between the materials, the results were consistent in the current study.

Other studies [39, 40] investigating stress distribution in maxillary central incisors restored with fibre, cast metal, and zirconia posts have reported that, in the fibre post models, stresses were distributed more homogeneously throughout the tooth structure, whereas in the cast metal and zirconia post models, stress concentrations were localised predominantly in the cervical–buccal regions and accumulated within the posts themselves. Furthermore, researchers have observed that the areas of maximum stress were located in the buccal middle third of the posts across all post types [41]. In terms of total deformation, the highest values were noted in the models restored with fibre posts. The elevated stress concentrations observed in the cervical and central regions of the root under occlusal loading conditions may contribute to an increased risk of root fractures—one of the most common complications associated with dental post applications. Notably, the maximum stress values, particularly those localised within the post material, are critical indicators for assessing the longevity of the restoration and the likelihood of clinical failure. These findings are consistent with the results of the present study.

Based on the findings of this study, equivalent stress concentrations were consistently identified in the buccal and palatal aspects of the cervical region of the tooth in all models subjected to loading. In line with previous FEA studies, it was further observed that stress tended to accumulate primarily at the initial point of load application, particularly in models where the applied force was localised rather than uniformly distributed over a broader surface area. These results corroborate and extend the observations reported in similar computational analyses [42].

Petcu et al. [43] were created two FEA models as a healthy maxillary central tooth and a maxillary central tooth with chronic apical periodontitis. The healthy tooth root was modelled in contact with the trabecular bone and the tooth with chronic apical periodontitis was modelled as granulation tissue to simulate resorption at the apical root. When they applied a force of 100 N and 300 N in the vertical direction to these models, they reported that the deformation caused by the force of 100 N was not clinically risky, but increasing the force to 300 N was critical in terms of deformation. Stress values in the models showed that stresses occurred in the cervical region of the tooth. When the total deformation in the models was evaluated, it was seen that the maximum value started from the incisal third of the crown and decreased towards the apex. The fact that the deformation intensifies in the incisal and decreases towards the cervical, and is supported by trabecular and cortical bone shows that the resulting deformation does not have a destructive effect on the tooth models. Despite the differences in modelling patterns, absence of post and restoration, the direction of force, elastic modulus, and Poisson's ratio in this study, both the regions where equivalent stress values are concentrated (except the region where the force is first applied) and the total deformation distributions are similar to the present study.

A FEA conducted on maxillary central incisors with chronic apical periodontitis and root resection models

demonstrated that apical resection procedures have a less pronounced impact on the biomechanical behaviour of teeth compared to periodontal bone loss [42]. In the present study, similar stress magnitudes and deformation patterns were observed, characterised by a progressive decrease in stress from the incisal edge towards the cervical region of the crown. These results align closely with the findings reported by Jang et al., reinforcing the reliability and reproducibility of the finite element methodology employed.

Belli et al. [44] reported that the stresses at the root tip increased with the size of the periapical lesion when they applied a force of 135° and 300 N to premolar tooth models with lesion diameters of 1 mm and 2 mm. In the study, it was suggested that the remaining tooth structure was preserved when the elastic modulus of the material used in the root canal was similar to dentin. In addition, it has been reported that when the elastic modulus of the material in the canal is high, it does not transmit the stress to the bone due to the bone defect in the periapical region but accumulates the stress in its structure and creates high-stress areas in the root. It was observed that the stresses accumulated on the material in cast metal and zirconia posts (Model 3, Model 4, and Model 5), while they were homogeneously distributed throughout the tooth in the fiber post model. Our findings align with those of Belli et al., reinforcing the credibility and validity of the present results within a comparable experimental framework.

In our study, the post-restored models demonstrated low stress magnitudes within the periapical lesion region and the surrounding trabecular bone, suggesting that these areas are relatively insulated from direct mechanical load transfer. Nonetheless, the long-term biomechanical effects of the lesion on adjacent tissues, and its potential influence on periapical healing dynamics, remain unclear and merit further in-depth investigation.

It has been suggested that post materials with an elastic modulus close to enamel or dentin will have a better stress distribution in the restored teeth [42]. However, this suggestion contradicts the present study and by studies showing [19, 39] that post materials with a higher elastic modulus than dentin strengthen the tooth structure and reduce the stress distribution in dentin. This is explained by the fact that materials with higher elastic modules absorb higher stress, resulting in lower stress at the tooth-post, and dentin-post interface but higher stress at the post. It was reported that the periapical condition was not affected by the post type in the 3–7-year follow-up of teeth with fiber and cast metal posts [45]. In a study with a follow-up period of 25 years [46] the retention time of cast post teeth in the mouth was the same as that of live and crowned teeth, and in a 17-year follow-up study [47] It was reported that there was no difference between the survival probability of restored teeth with and without cast metal posts.

A key limitation of this study lies in the inherent differences between the FEA model and the complex clinical reality of the oral environment. Specifically, factors such as thermal fluctuations within the oral cavity and the combined effects of static and dynamic masticatory forces could not be fully simulated. Moreover, in FEA studies, dental structures are typically standardised into idealised geometries; however, inter-individual anatomical variations can significantly affect biomechanical responses. Additionally, while the periapical lesion was modelled as a homogeneous structure for the purposes of this simulation, such lesions vary considerably in size, shape, and internal composition in clinical scenarios. Therefore, the numerical results generated by the FEA should be interpreted with caution, taking into account the simplified boundary conditions and assumptions to avoid misleading clinical extrapolations. Another important limitation is the lack of in vitro validation of the fracture resistance associated with the different post materials examined in this study. To strengthen the clinical applicability of these findings, future research should seek to validate the FEA outcomes through in vitro experiments or long-term clinical trials involving endodontically treated teeth with periapical lesions restored using various post systems.

Conclusions

This study underscores the significant impact of post material selection on stress distribution patterns in endodontically treated teeth with periapical lesions. Of the materials evaluated, fibre-reinforced posts exhibited biomechanical behaviour most comparable to that of an intact, healthy tooth under occlusal loading. Clinically, these results support the preferential use of fibre posts, as their ability to more evenly dissipate stress may help mitigate the risk of root fractures and improve the long-term survival of teeth with substantial structural loss.

Considering the inherent limitations of this study, the following conclusions can be drawn:

1. Due to their mechanical compatibility with dentine and their favourable stress distribution characteristics, fibre posts represent a biomechanically sound restorative solution, particularly for structurally compromised teeth affected by periapical lesions.
2. The presence of periapical lesions was found to decrease the overall stress magnitude within the root, primarily by reducing the mechanical integrity of the trabecular bone in the affected region.
3. Across all FEA models, occlusal loading resulted in stress concentrations predominantly in the cervical

third of the root, with the highest stress intensities localised within the post material, most notably in the fibre posts, underscoring their capacity to absorb and redistribute functional stresses effectively.

Abbreviations

FEA	Finite element analysis
RCT	Root canal treatment
CAD/CAE	Computer-aided design/engineering
PDL	Periodontal ligament
GP	Gutta percha
NiCr	Nickel chromium alloy

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Author contributions
Ömer Kırmalı: Conceptualization, Writing - Original Draft, Formal analysis, Mehmet Barış Akar: Methodology, Resources, Supervision, H. Kürşat Çelik: Investigation, Supervision, Kürşat Er: Methodology.

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Data availability
The datasets generated and analyzed during the current study are not publicly available due to (ownership of data) but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
None.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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