THE EFFECT OF TYPE POST, CROWN, AND FERRULE PRESENCE ON STRESS DISTRIBUTION OF MAXILLARY CENTRAL INCISORS WITH WEAKENED ROOTS: FINITE ELEMENT ANALYSIS

ABSTRACT

The aim of this study was to evaluate the biomechanical behavior, by means FEA, of maxillary central incisor with weakened roots restored with different posts, crowns and ferrule presence. A digital image of an intact maxillary central incisor section plane around the alveolar bone was obtained in order to build the model of sound tooth. A sound tooth and eight two-dimensional numerical models were generated from the protocol of image processing. The studied factors were: crown type - metal-ceramic crown (MC) and alumina-reinforced ceramic (CC); post type - glass fiber post (GFP) and cast post and core (CPC); and ferrule - absence of ferrule (AFE) and 2,0 mm ferrule (FE2). A 2N static and oblique load with a 135° inclination to the tooth longitudinal axis was applied at the level of palatal surface of the crown. The displacement was restricted and stress of tensile and compression within the tooth structure was recorded. Cast post and core models concentrated stresses in post dentin interface and glass fiber post models had homogeneous stresses distribution within the root dentin similar to sound tooth. The restorative complex GFP-CC concentrated higher stress in coping than GFP-MC, both models with or without ferrule. The ferrule presence improved the stress distribution regardless of the crown and post types. Therefore, cast post-and-cores concentrate too much stresses within a root dentin and post interface; glass fiber post has more homogeneous stress distribution in dentin than cast post-and-cores; the presence of 2 mm ferrule improves the mechanical behavior.

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KEYWORDS

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INTRODUCTION

Endodontically treated teeth are affected for higher risk of biomechanical failure than sound teeth[1] due to loss of tooth structure, instrumentation of canal root [2] and by changes of mechanical properties of dentin.[3] In case with loss of more than half of coronal tooth structure, the use of post-and-core is important to retain the restorations.[4] However, post space preparation become the root dentin weakened [2], which became the restoration of these teeth more complicated. [5-7]

Hence, it is important consider before the restorative technique the following factors: presence of ferrule, canal shape[5, 6, 8, 9], post length[10, 11] and diameter[11, 12], surface configuration[13], material of post-and-core[11, 13-19] and crown material.[20]

The characteristics of interface between post and dentin and the use of inappropriate posts, such as more rigid post material than dentin, like a cast post-and-core, may increase the fracture risk of remaining tooth structure, on the contrary of glass fiber post, which have an elastic modulus closer to dentin.[15, 21, 22]

However, glass fiber posts have standardized geometries and they are not well adapted to the weakened channel, resulting in inaccurate and a thick line of resin cement, compromising the longevity of restorative treatment. The adaptation of dowel in the weakened root canal can be obtained by relining with composite resin contributing to higher values of bond strength[23], reduced thickness of the cementation line leading to a lower polymerization shrinkage[23] and better distribution pattern of stresses.[24]

High stiffness materials just like alumina significantly withstand deformation, generating high stress concentrations at interfaces, modifying the biomechanical behavior of restorative system. On the other hand, metal-ceramic crown has been used with high rates of success for a long time with satisfactory mechanical properties.[25, 26]

Besides, the association with a composite resin cores simulates the natural flexural movements of tooth, reducing stress arising at the interfaces.[20]

The Finite Elements Analysis (FEA) method is an efficient tool to study the mechanical behavior of these associated factors, allowing the simulation of clinical situations and may being used to analyze and solve complex problems in biomechanical area.

It is important that physical properties being correctly represented, because FEA results depend on the size, placement and type of external loads, which induce the stress on the object of study. This method has been successfully employed to evaluate the mechanical behavior of teeth restored with different post systems[11-13, 15, 22, 27-29] and to investigate the influence of tooth preparation design on stress distribution in maxillary central incisors restored by means of alumina porcelain veneers when under functional loading.[21]

Within this context the hypothesis that the crown, post and amount of ferrule would influence the stress distribution in endodontically treated maxillary incisors with weakened roots must be checked.

MATERIAL AND METHODS

A two-dimensional (2D) finite element analysis was performed in order to evaluate the stress distribution in upper central incisor with weakened root canals varying the type of post, crown and presence or not of ferrule. A digital image of an intact maxillary central incisor section plane around the alveolar bone was obtained in order to build the model of sound tooth. The geometry and contours of this image were determined and established using the Mechanical Desktop AutoCAD V6 program (Autodesk, San Rafael, USA) (Figure 1).

Following the protocol of image processing described for the sound model, it was generated the restorative complex with a weakening of the root canal. It was simulated in order to remain a thickness of 0.5 mm of dentin around the cervical termination and its wear converged to a diameter of 2.5 mm at the apex of the post. The models restored with glass fiber posts were generated with composite resin around the dowel in order to fill the root canal weakened. The fiber post and the cast post-and-core were made to 10 mm in length. Eight numerical models were generated according to the amount of remaining tooth (absence of ferrule - AFE and 2 mm ferrule – FE2), type of dowel (Glass fiber-post - GFP and Cast post-and-cores - CPC) and restorative crown type (Metal Ceramic crown - MC and Glass-Infiltrated alumina all ceramic crown - CC). The restorative crowns were simulated with a coping of 0.5 mm thick.

The models generated in CAD software were exported in IGES format to finite element software (Ansys 12.0 – Ansys Inc., Houston, USA). The meshes of each structure were generated using specific software tools to refine and control its homogeneity. Areas with different material properties were identified and meshed with eight-noded isoparametric plane elements (PLANE183). A linear static analysis was performed and all structures and materials used were considered isotropic, elastic and homogeneous, and the properties were collected by literature (Table 1), except the glass fiber dowels, which were considered orthotropic (Table 2).

A 2N static and oblique load with a 135° inclination to the tooth longitudinal axis was applied at two adjacent nodes (1N each) at the level of palatal surface of the crown, simulating contact with the mandibular incisors in occlusion. Model displacements were restricted at external lateral outline and base of the bone structure in all directions.

Qualitative analysis of stress distribution was performed in accordance with Von Mises criteria and First Principal Stress.

Figure 1: Two-dimensional numerical model generated from sound tooth: (A) longitudinal slice of intact maxillary central incisor; (B) external and internal contour obtained in Mechanical Desktop AutoCAD V6 program; (C) plotted areas on finite element software (Ansys 12.0); (D) mesh created by mechanical properties of each structure; (E) load application on palatal surface.

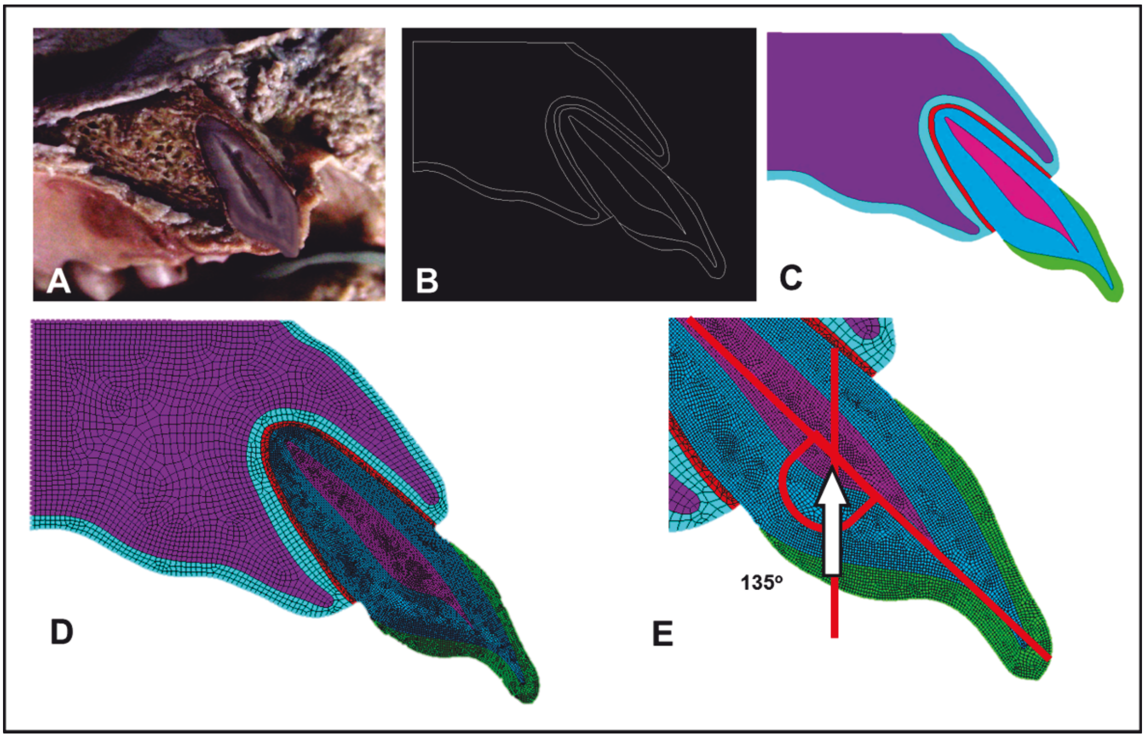


Table 1. Mechanical properties of dental structures and materials

Structure	Young's Modulus (MPa)	Poisson ratio	References
Trabecular bone	1370	0.30	12
Cortical bone	13,700	0.30	12
Periodontal ligament	68,9	0.45	12
Dentin	18,600	0.31	12
Enamel	84100	0.33	20
Pulp	2	0.45	41
Gutta-percha	0.69	0.45	12
Ni-Cr	205000	0.33	42
Composite resin	16,600	0.24	43
Feldspathic ceramic	69,000	0.30	20
Glass-Infiltrated alumina ceramic	418000	0.22	20

Table 2: Mechanical properties of glass fiber dowel.

Properties*	Glass fiber post	Reference
Ex (MPa)	37,000	*44
Ey (MPa)	9500	
Ez (MPa)	9500	
ηxy	0,27	
ηyz	0,27	
ηxz	0,34	
Gxy	3.10	
Gyx	3.10	
Gxz	3.50	

E= Elastic modulus; η= Poisson's ratio; G= Shear modulus; x,y,z= Specific orthogonal plane directions.

RESULTS

The 2D FEA analysis showed that regarding the type of dowel, there was stress concentration inside the CPC when compared with GFP groups. The models restored with GFP shows homogeneous distribution of stresses within the root dentin, but showed stress concentration within the coping for the CC and MC groups, and the first one had a higher degree of concentration when compared with the last one. The presence of 2 mm of residual tooth structure regardless of crown type and dowels improved the stress distribution pattern. All the models restored with CPC showed high tensile stress concentration into the root canal (figure 2).

DISCUSSION

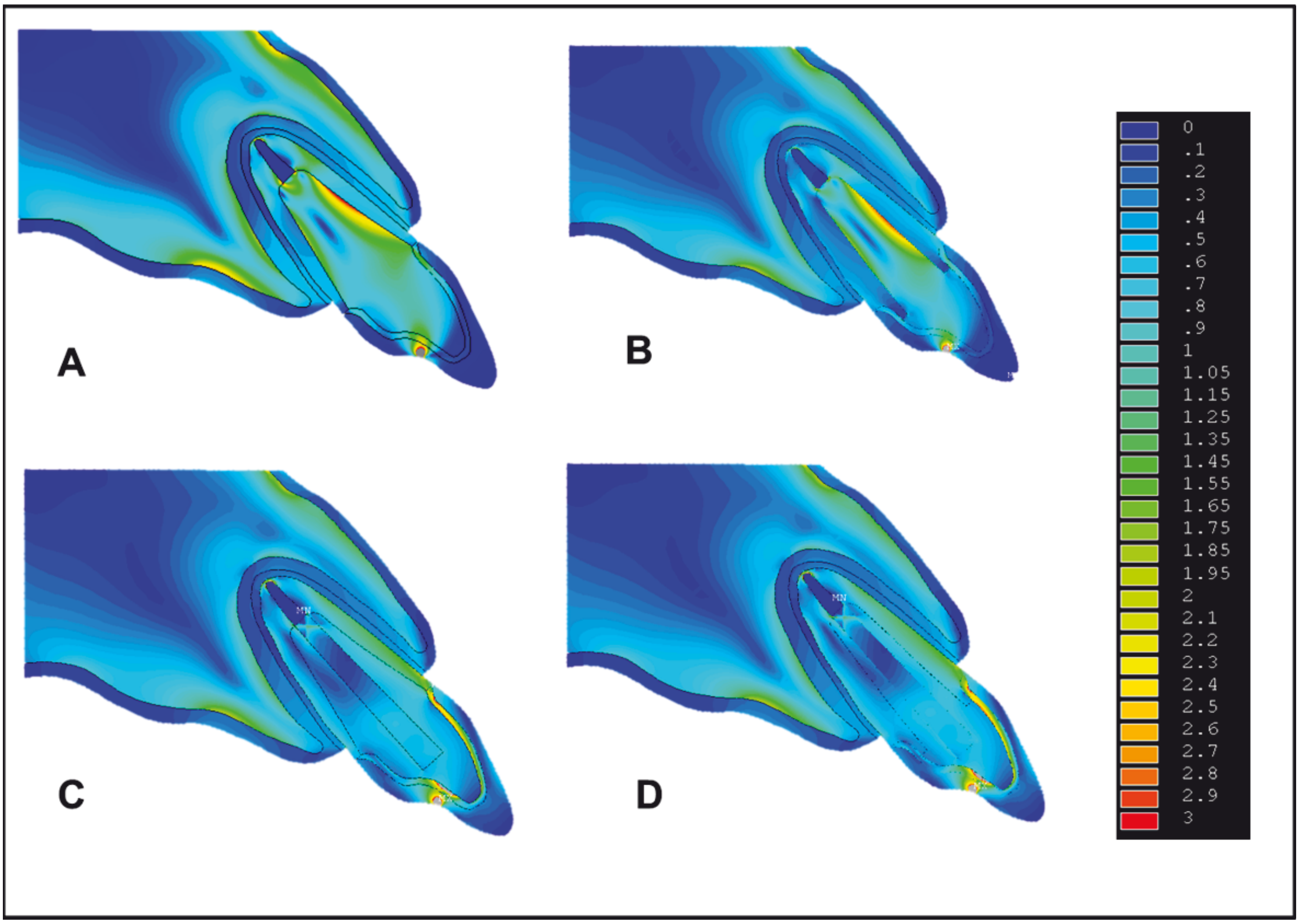
All hypotheses were accepted in this study. The type of post, crown and presence or absence of ferrule showed differences in stress distribution on teeth-restoration complex.

The teeth subjected to mechanical [30, 31] and chemical (Grigoratos et al. 2001) treatments during endodontic therapy decreased the fracture resistance, increasing the risk of irreparable fractures and tooth loss. [3] In these cases, it needs to use posts to retain the restoration. However, it is common the root canal therapy weaken roots, with wide canal and little dentin walls.

The choice of post and crown type should be discussed to find the restorative complex with biomechanical behavior similar to the sound tooth.[32] The current trend of aesthetic posts as the glass fiber posts is becoming increasingly popular. These materials have excellent physical properties such as translucency and mechanical properties like biomechanical behavior similar to dentin.[33] But the cast post and core are used widely by clinicians in adverse situations as in weakened roots.

The use of ceramic crowns reinforced metal-free is growing because the stiffness is increasingly high. In addition, studies showed the presence of 1mm ferrule is recommended in bonding procedures for core and all-ceramic crowns.[34]

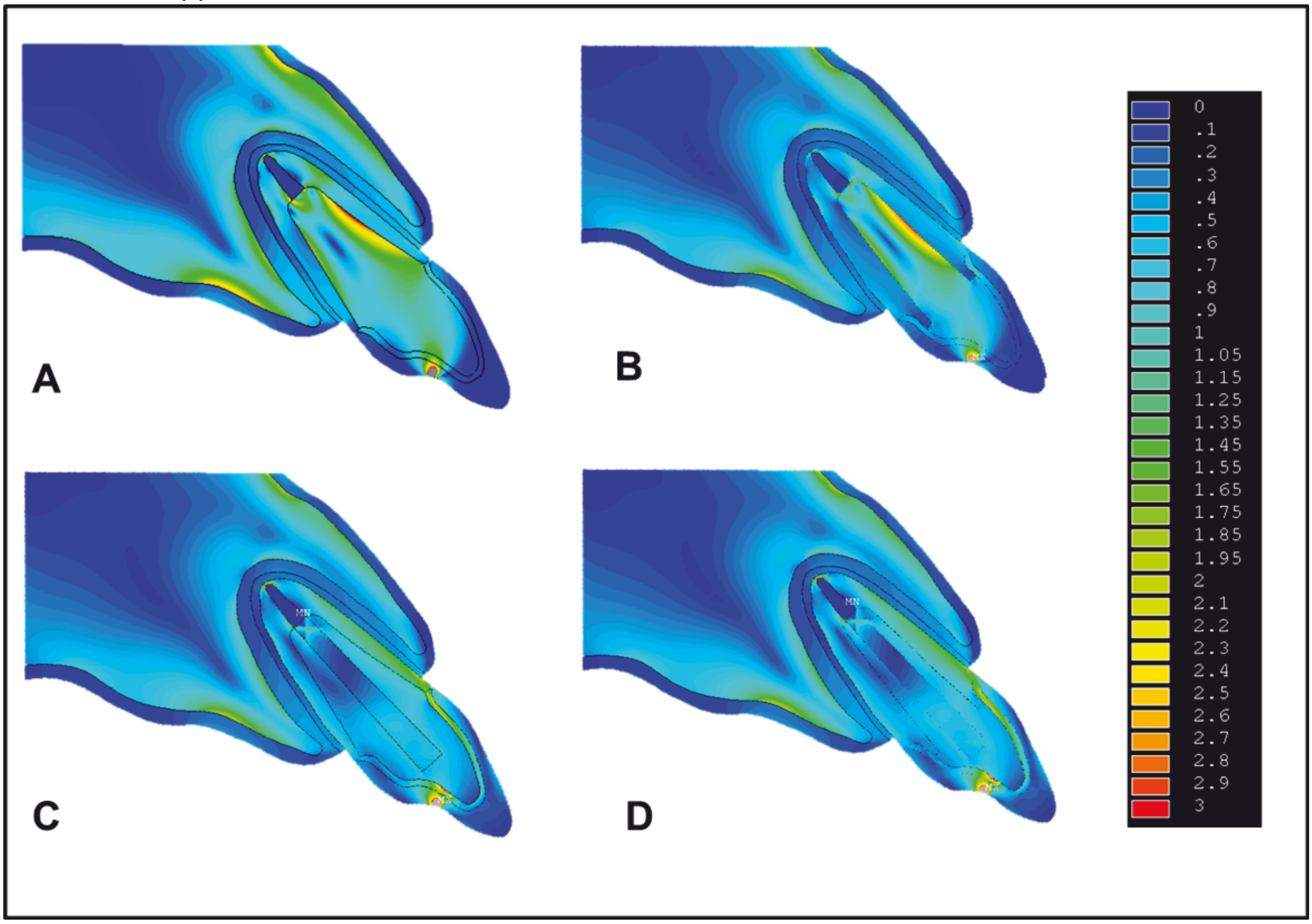
Figure 2: Stress levels and concentrations in tooth-restoration complex using Von Mises criteria. (A) Model AFE-CPC-CC; (B) Model RE2-CPC-CC; (C) Model AFE-GFP-CC; (D) Model RE2-GFP-CC.



Finite element method seems valid to evaluate the stress distribution for all studied factors. This method performs a numerical analysis computing, transforming a real problem on virtual. The used meshes follow the geometry of structures and the resolution of complex equations becomes possible through a variety of simple equations, which give the elements of an interconnection. The elements represent the discretization of model which is powered by mechanical properties of materials and loading restrictions. Thus, it is possible to solve a complex problem of stress-strain. Stresses are represented by criteria that convert results in color according to a pre-defined scale.

In this study were used the von Mises criterion and Maximum Principal Stress. The von Mises criterion is used for evaluating the distributed stresses distortionary in the model. It defined in this model where there is greater stress concentration without to qualify the stress in tensile and compression. This criterion was chosen to evaluate the behavior of complex tooth-post-crown and to show the high stress concentration into root canal and post-dentin interface, as shown in Figures 2A, 2B, 3A and 3B. It is due to the high stiffness or elasticity modulus of this material, which is a ratio of interatomic proximity. It transmits stress energy from material to substrate, according to specific and dependent geometry of model.[35, 36]

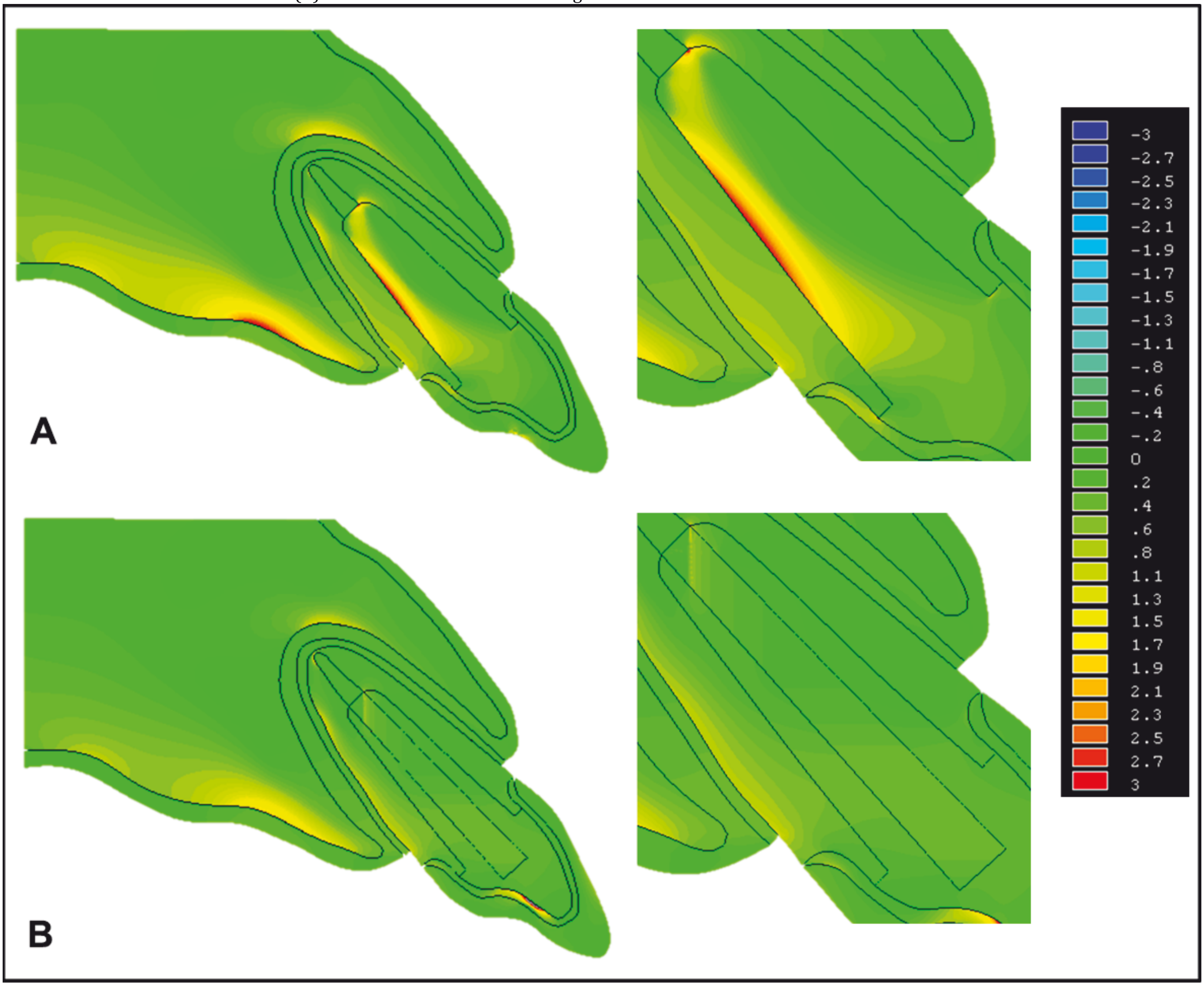
Figure 3: Stress levels and concentrations in tooth-restoration complex using von Mises criteria (A) Model AFE-CPC-MC; (B) Model RE2-CPC-MC; (C) Model AFE-GFP-MC; (D) Model RE2-GFP-MC.



This fact may indicate high risk of fracture for the presence of thin walls into the root canal. The failure in dentin due to endodontic treatment or preparation of root canal to the post concentrates stress at the apex of the post. So, the spread of failure is high, which can cause root fracture.[37, 38]

Since the glass fiber posts has the stress-strain relationship close to the dentin due to homogeneous energy distribution into the root and to reduce the risk of spread failures.[10, 13, 39] The models of this study simulated wide root canal restored with relined resin composite posts, as it is proposed in clinical cases. The elastic modulus of composite resin also has values close to the posts and dentin.

Figure 4- Stress levels and concentrations in tooth-restoration complex using 1ST Principal Stress. (A) Model RE2-CPC-MC showed high tensile stress concentration within the root canal. (B) Model RE2-GFP-MC with homogeneous distribution of stresses within the root canal.



On the Figures 2C, 2D, 3C and 3D are observed the relationship between the presence of glass fiber posts and stress concentration in the crown copings. This may be due to the difference in elastic modulus of restored materials, as the glass fiber post, NiCr alloy, glass-infiltrated alumina ceramic and feldspathic ceramic. The different stiffness provides a high stress concentration in materials with high elastic modulus, which are the copings in this study. In MC crowns (Figures 3C and 3D) the stress concentration in metal coping is lower than alumina coping (Figures 2C and 2D) due to the high elastic modulus of this ceramic. This study suggests that this feature may decrease the risk of root fracture.

The association between materials with high elastic modulus as the cast post and core, and metal or alumina copings (Figures 2A, 2B, 3A and 3B) has localized stresses concentrations at the load application point. It preserves the crown structure, but there is a high concentration in the cast post-and-cores and these stresses can generate damage for root. It is due to the similarity between the properties of post-and-core materials and coping.

The results for models with ferrule (Figures 2B, 2D, 3B and 3D) showed homogeneous stress distribution at root without high stresses concentrations in specific locations.[40] It can increase the root strength and avoid fractures.

In the analysis of Maximum Principal Stress, whose stress are qualified in tensile and compression stress, the results suggest that metal cores have concentrated high tensile stress in palatal surface of root represented by red color (Figure 4A). It is due to bending of tooth opposite and the oblique loading can spread fracture in the middle-cervical third root, where there are cracks.[37, 38]

This study shows a trend for clinical use of fiber glass posts, because they provide homogeneous stresses distribution at root, regardless of crown type. This evidence requires a laboratory validation of these results to prove the idea.

CONCLUSION

Within the limitations of this study, it is possible concluded that:

- In the finite element analysis, the cast post and core concentrate high stress into root canal and at post-dentin interface;
- The glass fiber post has homogeneous stress distribution in dentin;
- High stiffness copings concentrate high stresses within themselves, when associated with glass fiber posts;
- The presence of 2 mm ferrule may improve the stresses distribution in roots.

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