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Influence of diameter and intraradicular post in the stress distribution. Finite element analysis

Influência do diâmetro e do retentor intrarradicular na distribuição de tensões. Análise pelo método dos elementos finitos

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Resumo

Introdução: O comportamento biomecânico de dentes tratados endodonticamente é variável conforme o material restaurador selecionado e situação do dente a ser restaurado. **Objetivo:** Analisar por meio do método dos elementos finitos bidimensional o comportamento biomecânico de diferentes retentores intrarradiculares e diâmetros em dentes com 2mm de remanescente coronário. **Material e método:** Foram confeccionados seis modelos com três tipo de retentores: pino de fibra de vidro, pino de fibra de carbono e núcleo metálico fundido, ambos com diâmetro #1 (1,1mm de diâmetro) e #2 (1,3mm de diâmetro). A modelagem foi realizada através do programa Rhinoceros 4.0, e em seguida nos programas FEMAP 10.2 e NeiNastran 9.2 para desenvolvimento d os modelos de elementos finitos. Nos carregamentos foram utilizadas forças de 100N axial e oblíquo. Os resultados foram visualizados pelo mapa de tensão von Mises, e pela análise de variância (ANOVA) e pós-teste Tukey, com nível de significância à 5%. **Resultado:** O carregamento oblíquo apresentou maiores valores de tensões ($p<0,001$). O pino de fibra de vidro apresentou menores concentrações de tensões em ambos os carregamentos ($p<0,001$). O pino de fibra de carbono apresentou diferença significativa em relação ao núcleo metálico somente no carregamento oblíquo ($p=0,007$). O diâmetro não influenciou para o aumento de tensões dos retentores avaliados ($p=0,302$). **Conclusão:** Os pinos de fibras são mais favoráveis para restaurações de dentes tratados endodonticamente; O aumento do diâmetro não influenciou no aumento de tensões; A carga oblíqua é mais prejudicial à tanto para o retentor quanto para a estrutura dentária.

Descritores: Prótese dentária; técnica para retentor intrarradicular; prótese parcial fixa.

Abstract

Introduction: The biomechanical behavior of endodontically treated teeth depending on the selected restorative material and tooth situation to be restored. **Objective:** To analyze by the two-dimensional finite element method the biomechanical behavior of different diameters in intraradicular posts and teeth with coronal remaining of 2mm. **Material and method:** Six models were made with three types of posts, as follows: Glass fiber post, carbon fiber post, and cast metal post, both with diameter # 1 (1.1 mm in diameter) and # 2 (1.3 mm of diameter). The modeling was performed using the Rhinoceros 4.0 program. The FEMAP 10.2 and NEiNastran 9.2 programs were used to develop finite element models. The loading used was 100N for axial and oblique forces. The results were visualized using the von Mises stress map. The statistical analysis was made using analysis of variance (ANOVA) and Tukey post-test, with a significance level of 5%. **Result:** The oblique loading stress values were higher than the axial loading ($p<0.001$) for both situations. The glass fiber post showed the lowest concentrations of stress on both loads ($p<0.001$). The carbon fiber post presented significant difference compared to the cast metal post, only in the oblique load ($p=0.007$). The diameter did not increase the stress of the evaluated posts ($p=0.302$). **Conclusion:** The fiber posts were more favorable for restoration of endodontically treated teeth; the increase of diameter did not influence the increase of tension; the oblique load was more harmful for both posts and tooth structure.

Descriptors: Dental prosthesis; post and core technique; denture partial fixed.

INTRODUCTION

The use of an intraradicular post for endodontically treated teeth has been indicated frequently in the clinical routine for fixed restorations, since the tooth becomes more fragile and susceptible to fracture after endodontic treatment[1], especially in teeth with small amounts of coronal structure[2].

Among the methods used for the restoration of endodontically treated teeth, the methods that can be highlighted uses cast metal and prefabricated posts, particularly glass fiber and carbon fiber posts[3], and the choice of the retainer is usually based on the amount of remaining crown to be restored[4], and aesthetic in the rehabilitation of the anterior teeth.

In situations where there is only a small amount of remaining crown, the use of a cast metal post is preferred[5]. The high elastic modulus of the metal alloys used for casting could contribute to increased root fracture rates[3]. However, studies have reported that the use of a cast metal post has a similar success rate to the use of prefabricated fiber posts[6,7].

Currently, prefabricated posts have been increasingly used among clinicians and are considered favorable from an aesthetic point of view. They also reduce the treatment time because they eliminate the laboratory stage[6]. Fiber posts have the advantage of having an elastic modulus that is similar to the dentine[8] and translucency that favors cementing adhesive with a dual resin cement, which is capable of enhancing the retentivity within the root[9]. Another important feature is the preservation of the dentinary structure during the endodontic removal procedure, as the reduction of the dentinal wall could increase the chances of irreparable fractures[10]. However, few studies have investigated the influence of the diameter of the post for tooth resistance, and there is no consensus about this in the literature.

Thus, the aim of this study was to evaluate, using two-dimensional (2D) finite element analysis, the stress distribution in the use of a cast metal post, a glass fiber post, and a carbon fiber post of different diameters. The null hypotheses were tested: (1) there is no difference between intraradicular retainers evaluated in relation to stress distribution; and (2) there is no difference between the diameters of the different retainers in terms of stress distribution.

MATERIAL AND METHOD

Six models were simulated with the natural proportions of an upper central incisor and its constituent parts (crown / root) and the periodontal structure (alveolar bone and periodontal ligament). The bone tissues were obtained through a CT scan processed in InVesalius software (CTI, Campinas, SP, Brazil). The simplification of surfaces was realized through the Rhinoceros 4.0 software (Seattle, WA, USA), varying the retainer (glass fiber post, carbon fiber post, and cast metal post) and the diameter of the post (# 1 and # 2) (Table 1).

The different simulated retainers (glass fiber post, carbon fiber post, and cast metal post) showed similar preparations, with endodontic treatment without excessive wear on the internal walls of the dentine, with preparation of 2/3 length of root canal, leaving 3mm obturation of gutta-percha. The interfaces between the post, the restoration, and the coronal structure were filled with resin cement of a 0.1 mm thickness[11].

The diameter of the retainer used was simulated with thickness size #1 (1.1 mm in diameter and 0.7 mm in the apical tip) and #2 (1.3 mm in diameter and 0.9 mm at the apical tip) with dimensions obtained from a post Angelus (Reforpost - Angelus, Londrina / PR, Brazil). All simulated teeth had coronary remaining ferrule of 2 mm.

The coronal restoration was simulated with an injectable ceramic material (lithium disilicate - IPS Empress II) built from the outer contour of the natural crown of the dental element. Full peripheral preparation was performed with a wide chamfer and with a conventional thickness of this type of restoration (2 mm to the incisal, 1.5 mm to the vestibular, and 1.2 mm to the palatal portion).

After preparation of the drawings, they were exported to FEMAP 11.0 software (Siemens PLM Software, Plano, TX, USA) for incorporation of the attributes according to the mechanical properties of each material (Table 2). Moreover, the meshes of the finite element models were generated, with all the materials

Table 1. Specification of the models used in this study

Model	Loading	Description
1	Diameter #1	Tooth with treated canal, reconstructed with **glass fiber post** and filling core with 2 mm ferrule, restored with metal-free crown.
2		Tooth with treated canal, reconstructed with **carbon fiber post** and filling core with 2 mm ferrule, restored with metal-free crown.
3		Tooth with treated canal, reconstructed with **cast metal post** and filling core with 2 mm ferrule, restored with metal-free crown.
4	Diameter #2	Tooth with treated canal, reconstructed with **glass fiber post** and filling core with 2 mm ferrule, restored with metal-free crown.
5		Tooth with treated canal, reconstructed with **carbon fiber post** and filling core with 2 mm ferrule, restored with metal-free crown.
6		Tooth with treated canal, reconstructed with **cast metal post** and filling core with 2 mm ferrule, restored with metal-free crown.

Table 2. Mechanical properties of simulated materials

Structure/ Materials	Elastic Modulus (GPa)	Poisson Ratio	References
Enamel	41.0	0.30	Ko et al.[12]
Dentine	18.6	0.31	Ko et al.[12]
Pulp	0.0005	0.45	Genovese et al.[13]
Periodontal ligament	68.9 × 10 –3	0.45	Ko et al.[12]
Cortical bone	13.7	0.30	Ko et al.[12]
Trabecular bone	1.37	0.30	Ko et al.[12]
Gutta-percha	0.69 × 10 –3	0.45	Ko et al.[12]
Resin cement and Filling core	7.0	0.30	Genovese et al.[13]
Glass fiber post	40.0	0.22	Durmus et al.[8]
Carbon fiber post	125.0	0.25	Chuang et al.[14]
Cu-Al alloy	109.08	0.33	Coelho et al.[15]
IPS Empress	65.0	0.30	Imanishi et al.[16]

considered homogeneous, isotropic, and linearly elastic after analysis in a plane state of tension.

Loads were simulated in the axial and oblique directions, with 100N load applied approximately 2 mm below the incisal edge (natural point of contact) in both situations. The axial load was applied parallel to the simulated tooth, while the oblique loading was undertaken at a 30° angle related to the long axis of the tooth. The models were fixed in the upper base of cortical bone in the x and y directions, preventing the movement of this base. The stress generated by loading applications were distributed internally in the simulated structures (Figure 1). After generating the analyses in the finite element software, they were calculated using NEiNastran 9.2 (Noran Engineering, Inc., Westminster, CA, USA) software. The results were then imported again into the finite element software for plotting the maps of the von Mises stress.

Three-way (retainer, diameter, and loading) analysis of variance (ANOVA) and the Tukey post-hoc test were used to analyze the interactions between the main results with the statistical software (Sigma Plot 13; Systat Software, Inc) ($p<0.05$).

RESULT

Concerning simulated loading, the oblique loading showed higher stress values in comparison with the axial load ($p<0.001$). The glass fiber post showed lower stress concentrations in comparison with the carbon fiber post and the cast metal post for both loads ($p<0.001$). Under the axial load, there was no significant difference between the carbon fiber post and the cast metal post ($p=0.133$), but with the oblique loading, the carbon fiber post showed better stress distribution than the cast metal post ($p=0.007$). The diameter showed no significant influence on the stress distribution of the retainers ($p=0.302$) (Figure 2).

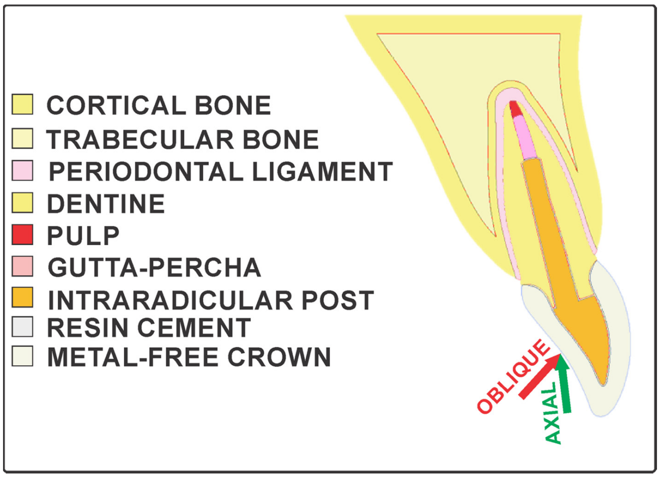

Figure 1. Description of the simulated model for analysis.

DISCUSSION

The first null hypothesis was rejected, because better stress distribution was observed in the glass fiber post models. This result corroborates other studies that have demonstrated advantages to the use of the glass fiber post under different biomechanical tests[2,17-20], reinforcing the assertion that in clinical situations, such as those simulated in this study (coronal structure with ferrule of 2 mm), the ferrule presence was an essential condition for the success of the prosthetic restoration[2,5].

There are some factors that may have contributed to this more homogeneous tension distribution in the glass fiber post. The main factor relates to the elastic modulus of this material, which is closer to the dentine structure[19]. Thus, when material shows higher elastic modulus, as the cast metal post and the carbon fiber post there is stress concentration in the retainer[21]. In addition, the low modulus of elasticity could influence the greater stress transferred to the tooth structure[8]. However, in this study, higher stresses were not observed in the root region when the tooth was restored with the glass fiber post.

In this context, besides the better stress distribution along the glass fiber post, some authors have found that the fracture of the glass fiber post, which is due to the flexibility of the material, is more favorable in terms of avoiding catastrophic failures such as fractures in the middle or apical dental root. The latter commonly occur in materials with a high modulus of elasticity[2,20,21]. It should be emphasized, however, that, in this study, the simulation was performed only on a single restoration unit considering a single unit of restoration. Factors such as the increased load on the tooth, which is observed in retainers of removable dentures, can increase this stress distribution. Thus, it is important the performance of new studies to evaluate these situations.

The stress distribution on the carbon fiber post showed similarity with that of the cast metal post under axial loading. These results may have been influenced by the use of a metallic alloy such as

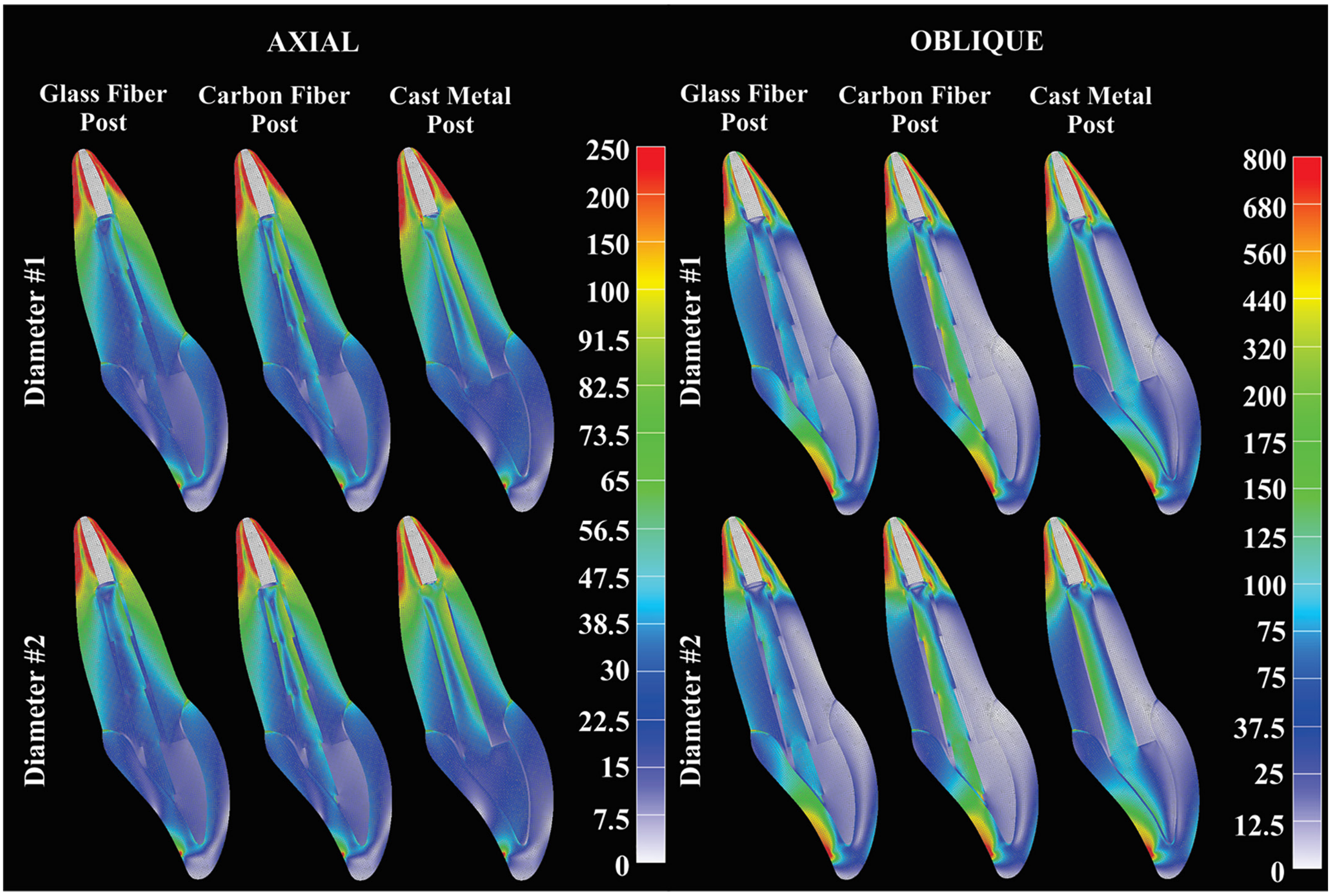

Figure 2. von Mises stress distribution under axial and oblique loading.

copper-aluminum, which exhibits an elastic modulus close to that of the carbon fiber post[14,15]. Therefore, it is recommended to avoid the use of an alloy that has a high elastic modulus, such as the Ni-Cr[2], as this has approximately twice the stiffness. The high elastic modulus could enhance the stress concentrations for the retainer and the tooth, especially in the case of oblique loading, as a significant difference was observed for the cast metal post compared to the other retainers.

The second hypothesis was accepted, as there was no observed influence of the diameter of the post on the stress distribution of the retainers. In this study, the intraradicular wear were considered with standardized dimensions, as there was no influence of the root resistance (maximum 1/3 of the buccolingual diameter)[10]. Furthermore, the increase in the diameter of the retainers was only 0.2 mm (diameter # 1 to # 2). In situations where the dentin structure exhibits greater wear (more than 0.2 mm), it would be necessary to use a post with a larger diameter, and this could directly influence the stress distribution[22].

Thus, for the glass fiber post, the clinician should be expected to use the diameter that best fits the root canal, whereas, when the prepared root canal it is greater than diameter of the post, the most suitable method is to use accessories post or to use the technique of relining post[10]. For the cast metal post, on the other hand, a suitable preparation (2/3 of the root implantation) and a minimum axial thickness of the walls is essential to avoid catastrophic failure[10].

The finite element method has been used to identify the selection of the post, to perform the failure analysis, and consequently, to facilitate the treatment prognosis. However, the limitations of this methodology must be recognized. Although the three-dimensional method is preferable to more complex structures, the two-dimensional method is effective when it comes to comparing the biomechanical aspect of a single unit tooth, which is acceptable for analyzing the results[23,24]. This can be done without depending on the computational capacity of high-performance processing due to the simplification of the mathematical calculation[25].

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn: 1) The glass fiber post showed better stress distribution when compared with other retainers; 2) the increase of the simulated diameter showed no significant influence on the stress distribution; and 3) the oblique loading was more harmful to the root and the retainers.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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