

Effect of the post geometry and material on the stress distribution of restored upper central incisors using 3D finite element models. Stress distribution on incisors with posts

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This study evaluated the effect of geometry and material of posts on the stress distribution in maxillary central incisors, using the finite element method. Four 3D models were developed: (i) healthy tooth and restored teeth using (ii) tapered, (iii) cylindrical and (iv) two-stage cylindrical posts. Materials used were stainless steel, titanium, zirconium dioxide, carbon and glass fibers on Bis-GMA matrix. Two stress concentration regions were verified: (i) adjacent to the alveolar bone crest and (ii) dentin-post boundary. Tensile and compressive stresses were concentrated on the palatal and facial surface, respectively, for all the analyzed models. In the dentin portion close to the alveolar bone crest, different anatomical form and material posts presented similar patterns of stress distribution. However, in the dentin-post boundary, more favorable results were presented by glass fibers and carbon fibers posts, followed by titanium, being the worst results associated to the use of stainless-steel or zirconium dioxide posts. Still in the dentin-post boundary, tapered posts presented more favorable results than cylindrical posts, followed by two-stage cylindrical posts, which presented the highest levels of stress concentrations. It was concluded that the insertion of post alters the pattern of stress distribution when compared with the healthy tooth and that smaller stress concentrations are associated to the use of glass fiber or carbon fiber tapered posts.

Key words: Finite element method, incisors, posts, stresses

The teeth become weak with the aging, due to decay, abrasion, fractures and restoration procedures.^[1] Cavity preparation and endodontic treatment increase the fracture potential of the remaining tooth structure, due to its volume reduction and loss of nutrient supply from dental pulp.^[2] Therefore, the use of posts is needed for retention of the core materials.^[3]

The reinforcement of this structure has been another attribution of the prefabricated posts, although the literature presents studies in which the use of posts can induce increase, decrease or not alter in the susceptibility of the tooth to fracture.^[4-8] In the attempt of describing the structural effects of posts, researchers have used several types of laboratory techniques, including the finite element method (FEM).^[7,9,10-13]

The objective of this study is to evaluate the effect of the geometric form and material of the post in the stress distribution in a central maxillary incisor.

MATERIALS AND METHODS

The FEM was used in this study. This method is suitable for the studied problem since it allows a detailed analysis of complex structures composed by different materials as the biological structures. The program used was ANSYS (Swanson Analysis Systems, Houston, Pa.), executed in a personal microcomputer (PC).

Four 3-D geometric models were obtained having as reference the anatomy of the central maxillary incisor presented by Wheeler^[14] [Figure 1]. The model 1, representing a healthy tooth, includes domains for the enamel, dentin, pulp, cortical bone and spongy bone. The modeling of the pulp and the root channel was based on the anatomy presented by Cohen and collaborators.^[15] The models 2, 3, and 4, respectively represent teeth reconstructed with tapered, cylindrical

and two-stage cylindrical posts, including domains for the porcelain crown, resin composite core, post, gutta-percha, remaining dentin, cortical bone and spongy bone. The consideration of a larger number of domains seeks to simulate the conditions found in oral cavity with larger precision, making possible to reach results closer to reality. The cement was considered as integral part of the radicular dentin due to its small thickness and mechanical properties similar to the dentin. The non-consideration of the cement as an isolated structure was previously analyzed.^[4,7,16,17] The periodontal ligament was not considered due to three reasons: its small thickness, the controversy in relation to the values of its mechanical properties and the limited impact of its presence in the stress distribution in dentin. Such conduct was previously adopted.^[8,16-18] According to Rubin and collaborators,^[18] the periodontal ligament has considerable influence when considered the stresses on the supporting bone structures, having little impact on the stresses in dentin. The anatomy of the tapered post was based on the form of the Unimetric post (Les Fils D, Auguste Maillefer S.A. - Baillaigues - Switzerland) with length of 12 mm and diameters of 1.0 mm and 2.0 mm in the extremities. The cylindrical post was considered having a 1.4 mm diameter and 12 mm length. The two-stage cylindrical post was based on the anatomy of the C-Post (Bisco, Itasca, IL) with length of 12 mm, larger diameter of 1.8 mm and smaller diameter of 1.2 mm. Posts made of stainless steel, titanium, zirconium dioxide, carbon fiber in Bis-GMA matrix and glass fiber in Bis-GMA matrix were analyzed and results were later compared with the healthy tooth analysis. The material properties necessary for the study (Poisson's ratios and Young's moduli) are presented in Table 1. Considering that the properties of zirconium

dioxide are identical to the stainless steel, the results for the stainless steel posts were extended to the zirconium dioxide posts.

The obtained models were analyzed in the domains of 3-D elasticity and some simplifications were established. It was assumed that all materials were homogeneous and isotropic, presenting linear elastic behavior, except the carbon fibers and glass fibers posts, considered orthotropic.

In this work, 10-node-tetrahedral elements were used. An illustration of the external surface meshes of the dental structure can be observed in Figure 2. The models 1, 2, 3 and 4 were generated respectively with 8,934; 8,001; 8,554 and 8,015 nodes and with 47,292; 41,721; 44,239 and 41,799 elements.

A load of 100N was applied to the models at approximately 2mm from the incisal margin of the palatal surface, with an angle of 45° with respect to the longitudinal axis of the tooth, to simulate the mastication force [Figure 2], as previously applied.^[7,8] The nodes in the upper portion of the cortical bone were constrained, as well as the nodes belonging to the cortical bone adjacent to the contiguous teeth as shown in Figure 2.^[17]

Considering the larger susceptibility of dental fracture due to tensile loads, the stress in the long axis of the tooth (δ_y) was adopted in the analysis [Figure 2]. The information about the type of stress induced by the insertion of the post is indispensable, once the dental structures (as the enamel and the dentin) and restoring materials (as the porcelain) present low tensile strength and high compressive strength.^[4] Therefore, the stress field along the Y axis (δ_y) was selected to identify the type of stress generated (tensile or compressive) due to the nature of the problem (similar to bending of a cantilever beam), leading to a posterior identification of the maximum and minimum principal stresses.

Table 1: Material properties

Material	Young's modulus (GPa)	Poisson's ratio	Author
Enamel	41	0.30	Ko <i>et al.</i> , 1992
Dentin	18.6	0.31	Ko <i>et al.</i> , 1992
Pulp	0.002	0.45	Rubin <i>et al.</i> , 1983
Cortical bone	13.7	0.30	Ko <i>et al.</i> , 1992
Spongy bone	1.37	0.30	Ko <i>et al.</i> , 1992
Porcelain	69	0.28	Yaman <i>et al.</i> , 1998
Resin composite core	22.2	0.30	Cohen <i>et al.</i> , 1996
Guta-percha	0.00069	0.45	Ko <i>et al.</i> , 1992
Stainless steel	200	0.33	Ko <i>et al.</i> , 1992
Zirconium dioxide	200	0.33	Ahmad, 1998
Titanium	103.4	0.33	Clelland <i>et al.</i> , 1991
Carbon fiber/Bis-GMA matrixparallel to fibers	129	0.33	Manufacturer
Carbon fiber/Bis-GMA matrixperpendicular to fibers	9.62	0.33	Manufacturer
Glass fiber/Bis-GMA matrixparallel to fibers	50	0.33	Rengo, 1999
Glass fiber/Bis-GMA matrixperpendicular to fibers	9.62	0.33	Manufacturer

RESULTS AND DISCUSSION

After processing the models and obtaining the results, it was verified, through the analysis of the stress diagrams (δ_y), two distinct tensile stress concentration regions in dentin: (i) Region A - cervical region adjacent to the alveolar bone crest and (ii) Region B - region of the dentin-post boundary [Figure 3].

The results of the 3-D analyses are displayed in Table 2, where the maximum values of δ_y are shown for the two stress concentration regions. A concentration of tensile stresses was verified on the palatal surface, in the dentin portion close to the alveolar bone crest (Region A) and also in the dentin-post boundary (Region B). Such observations were made for all the studied models: healthy tooth and teeth restored with posts. [Figure 4] presents the stress distribution δ_y for the models considering the placement of the post.

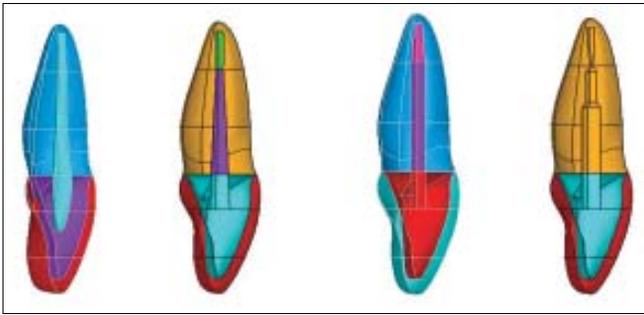


Figure 1: Simplified 3-D geometry. From left to right, models 1, 2, 3 and 4

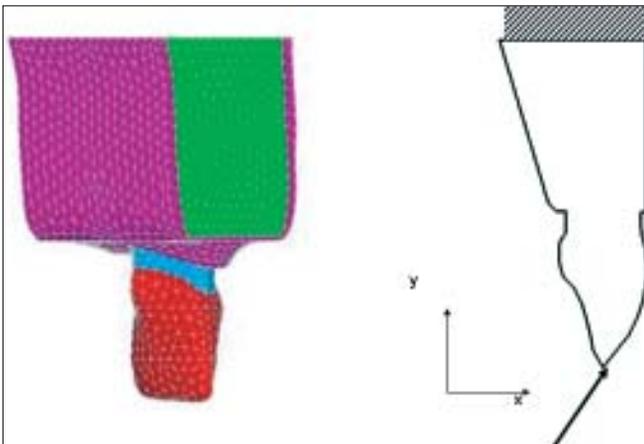


Figure 2: External surface mesh of the studied models and applied load at the cross section



Figure 3: Tensile stress concentration regions

Considering region A (dentin portion adjacent to the alveolar bone crest on the palatal side), the insertion of a post did not induce significant variations in the stress concentration with respect to the healthy tooth [Figure 4]. Decrease in the stress values was generally observed for the region A. However, small increase in the tensile stress was observed for the carbon fiber and glass fiber posts and in the two-stage cylindrical shape [Table 2, Figure 4]. Such results can be explained by the lower modulus of composite materials, as well

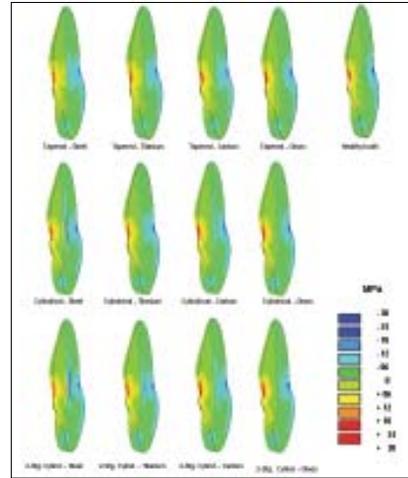


Figure 4: Stress distribution on the models with posts lingual-facial cross sections

Table 2: Maximum longitudinal stresses (σ_y) values on the different stress concentration regions

Region	Post shape	Post material	A σ_y (MPa)	B σ_y (MPa)
	Healthy tooth		28.4	1.0
Tapered		Steel	27.3	12.1
		Titanium	27.8	7.3
		Carbon fiber	28.2	4.5
		Glass fiber	28.7	4.3
Cylindrical		Steel	27.3	25.3
		Titanium	27.7	10.0
		Carbon fiber	28.3	7.4
		Glass fiber	28.2	1.5
Two-stage cylindrical		Steel	28.3	32.6
		Titanium	29.2	14.9
		Carbon fiber	30.4	10.9
		Glass fiber	30.4	8.5

Obs.: Region A - Adjacent to the palatal bone crest region B - Dentin-post boundary

as for the orthotropy presented by these materials. Such posts present moduli approximately two times lower to dentin modulus when considered the perpendicular plan to the long axis of the posts. For the region A, although there were alterations in the stress patterns when posts of different materials and geometric forms were used, such alterations were clinically negligible. It can be seen from Table 2 that dentin tensile stress concentration levels are significantly higher on the region of palatal bone crest (Region A) compared with the post-dentin boundary (Region B). Moreover, the insertion of any post did significantly not change these stress concentration levels, which are also present on the healthy tooth. This indicates that there must be a stress dissipation mechanism not considered on the studied models. Periodontal ligament and interstitial fluid between the tooth and the bone may be responsible for damping effects that could dissipate these high stress concentration levels on the real structure. Therefore, this work should focus more

on the post-dentin interface tensile stress concentration (region B), where failure is more likely to initiate.

Observing region B (dentin-post boundary), increase in the stress level was noticed with the placement of a post with respect to the pulped tooth. In relation to the material, the glass fiber posts presented the smallest stress concentration levels, followed by carbon fiber posts, titanium posts and stainless steel posts [Figure 4]. Considering the geometric form, tapered posts presented the smallest stress concentration levels, followed by cylindrical posts and two-stage cylindrical posts. Similarly to the results found in this study, Albuquerque and collaborators^[8] observed smaller concentration of tensile stresses in the dentin-post boundary on the palatal surface, when posts with smaller modules were used. Stainless-steel posts presented the largest levels of tensile stress concentration, also corroborating the results of Albuquerque and collaborators.^[8] Similarly, Cailleteau and collaborators^[4] analyzing the effects of the insertion of a stainless steel post in the stress distribution in incisors through 2-D models, found a concentration of compressive stresses on the facial surface and of tensile stresses on the palatal surface both for the healthy tooth as for the restored tooth, confirming the results presented in this work. Cailleteau and collaborators^[4] also verified an increase of 102% in the tensile stress along the internal border of the channel with respect to the healthy tooth, leading them to conclude that the insertion of a post should not be a routine procedure if there is remaining dental structure. Corroborating the results presented in [Figure 4], Rengo^[19] found smaller tensile stress concentrations associated to the use of quartz fiber posts, followed by carbon fiber posts and for stainless steel posts, which presented the largest level of tensile stress concentrations. This author points out that the use of a highly stiff material results in a non-homogeneous stress distribution, which leads to the emergence of regions of concentrated stresses. Cohen and collaborators,^[15] using photoelastic stress analysis, affirmed that the most stable post-system is the one, which distributes the stress in a more symmetrical way and that an asymmetric stress pattern can cause the premature failure of the post. Using the same methodology, Caputo and Hokama^[20] found a more uniform stress distribution with the increase of the diameter and length of the post. Such a discovery is in agreement with that of Peters and collaborators^[21] concluding that preference should be given for larger diameter cylindrical posts, as long as the clinical limits are respected.

Great emphasis has been given in the development of projects where the pattern and the resistance to fracture of teeth restored or not with posts are determined. Using the mechanical stress analysis, Guzy and Nicholls^[22] mentioned that there was not significant

difference in the load values, pattern and location of fractures among teeth with or without posts, pointing out, however, that teeth without posts are more resistant than those with posts. Sidoli and collaborators^[23] and Dean and collaborators^[24] found larger resistance to fracture in teeth where posts were not used. Dean and collaborators^[24] also affirmed that the amount of remaining dental structure is more important in the determination of the resistance to fracture than the form or the material of the post. Such results corroborate the present analysis, which indicates lower strength for the restored teeth and can be justified by the stress concentrations introduced by the posts.

When the influence of the geometric form and consequently of the adaptation of the post to the root channel was considered, Sorensen and Engelman^[25] mentioned that the largest resistance values and the largest incidence of fractures on the apical portion of the root are associated to the use of tapered posts, best adapted to the root channels. However, Assif and collaborators^[26] pointed out that the load necessary for the fracture of such teeth was much larger to those found in the buccal cavity. Therefore, relating the conditions in the buccal cavity and the simulated ones in this study, a better behavior is foreseen for the tapered posts in relation to the cylindrical and two-stage cylindrical.

Using 3-D finite element models, Yaman and collaborators^[17] affirmed that the material of the core was more important than the post itself and that the alteration in the material of the post does not cause modification in the level and the distribution of the stresses when the material of the core is maintained. Such results are in disagreement to the findings on this study, since same simulated crowns and resin composite core in all the cases led to different behaviors of the studied posts.

Concerning the material of the post Sidoli and collaborators^[23] found smaller incidence of extensive fractures in teeth restored with carbon fiber posts (40%), while the same kind of fractures were observed in 100% of the cases of teeth restored with cast metal posts. Similar condition was verified by Martines-Insua and collaborators^[27] that observed only 5% of root fractures in teeth restored with carbon fiber posts, being the remaining 95% due to the displacement of the posts or of the core or of the whole system. Yet for the metallic posts, 91% of root fractures were verified. Still studying the influence of the material of the post in the resistance to fracture, Mannocci and collaborators^[28] found similar behavior between carbon fiber and carbon-quartz fiber posts, being such behavior better than that presented by zirconium dioxide posts. Such results took the authors to conclude that the posts made of composite materials were capable to reduce to the minimum risk of root fracture. Also comparing posts

of composite materials (carbon and glass fiber) with zirconium dioxide posts, Maccari^[29] found close results among posts of composite materials concerning the type and the value of the load necessary for the fracture, which was characterized by the resin crown fracture. Yet for the zirconium dioxide posts, 100% of the flaws were characterized by fracture of the crown and post, from which 30% involved root fractures. Such discoveries validate the ones of the present work, once smaller tensile stresses in the dentin-post boundary were observed in composite material posts compared to cast metal posts.

The flexibility of the post-core system presents as advantages the smaller stress on the root structure and consequently smaller risk of root fracture, having as disadvantages the larger risk of marginal infiltration in the tooth-restoration boundary, as well as the displacement of the whole set Mondelli.^[30] A flexible post can be unfavorable, especially when there is a small remainder of dental structure between the margin of the core and the extension gingival of the artificial crown. When the ferrule effect is absent or extremely reduced, occlusion loads can cause the deflection of the post, with small movements of the core and with fracture of the cement, leading to the displacement of the whole set in a small space of time.

The results of this study are in agreement with Boudrias and Sakkal^[31] that affirmed that the ideal form of a post should satisfy some conditions, among which to allow conservative preparation of the channel, to provide retention and resistance to displacement and to induce minimum transmission of stress to the remaining dental structure.

CONCLUSIONS

From the results presented it may be concluded that:

- The insertion of a post altered the pattern of stress distribution when compared to the healthy tooth;
- The placement of a post induced elevation in the stress concentration in the dentin-post boundary;
- In the dentin-post boundary, glass and carbon fiber posts presented more favorable results; Titanium posts presented larger stress concentration than the composite material posts. The worst results are associated to the use of stainless steel or of zirconium dioxide posts;
- In the dentin-post boundary, tapered posts presented more favorable results than cylindrical posts; two-stage cylindrical posts presented the largest concentrations of tensile stresses.

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