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Influence of Post and Resin Cement on Stress Distribution of Maxillary Central Incisors Restored with Direct Resin Composite

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Clinical Relevance

According to finite element analysis, the zirconia ceramic post created higher stress levels in the post and slightly less in dentin compared with glass fiber posts. Resin cement with a high elastic modulus created higher stress levels in the cement layer. The different film thicknesses of cement did not create significant changes in stress levels.

SUMMARY

The current study evaluated the influence of two endodontic post systems and the elastic modulus and film thickness of resin cement on stress distribution in a maxillary central incisor (MCI) restored with direct resin composite using finite element analysis (FEA). A three-dimensional model of an MCI with a coronary fracture and supporting structures was performed. A static chewing pressure of 2.16 N/mm^2 was applied to two areas on the palatal surface of the composite restoration. Zirconia ceramic (ZC) and glass fiber (GF) posts were considered. The stress distribution was analyzed in the post, dentin and cement layer when ZC and GF posts were fixed to the root canals using resin cements of different elastic moduli (7.0 and 18.6 GPa) and different layer thicknesses (70 and 200 µm). The different post materials presented a significant influence on stress distribution with lesser stress concentration when using the GF post. The higher elastic modulus cement created higher stress levels within itself. The cement thicknesses did not present significant changes.

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INTRODUCTION

A persistent problem that occurs in restorative dentistry is fractures that occur in vital or pulpless teeth.[1-2] Endodontically-treated teeth are affected with a higher risk of biomechanical failure when compared to vital teeth.[3-4] The access preparation for endodontic treatment removes the roof of the pulp chamber, which may account for the relatively high fracture incidence documented in pulpless teeth.[5] To restore an endodontically-treated tooth for crown retention when insufficient coronal structure remains, use of the root canal space may be required for retention of the core and subsequent restoration.[6]

Depending on the coronal tooth structure that remains and the technique used (direct or indirect), endodontic anchorage can involve either a cast post and core or a prefabricated post. Analysis of the available literature shows that the main function of the post is to anchor the core to the root, providing little to reinforce the root.[7-10] Moreover, some authors state that posts may interfere with the mechanical resistance of teeth, increasing the risk of damaging the remaining tooth structure.[11] The role of posts in maintaining the core material is particularly relevant for posterior teeth, where masticatory loads are essentially compressive.[12] However, when loaded transversely, as in the case of incisors, the flexural behavior of posts should be carefully considered.[13] The maxillary central incisor (MCI) mechanically behaves like an elastic beam fixed at one end during function and as a cantilever when not loaded along its longitudinal axis. In this failure scenario, post and core flexural and torsional characteristics should receive more research interest.[14-16]

The practitioner's selection of materials and restorative techniques are difficult, due to the number of options available. Anterior teeth should fulfill the demand of an aesthetic restoration; therefore, practitioners sometimes resort to using all-ceramic crowns or a direct composite. When prefabricated posts are indicated, many alternatives are present. In all-ceramic crowns and direct composite restorations, esthetic posts are preferred, which include zirconia ceramic (ZC) and glass fiber (GF) posts.[17] A ZC post can offer superior strength when compared with a GF post.[17-18] However, it is commonly accepted that post systems with an elastic modulus similar to that of dentin and core have better biomechanical performance.[19] In addition, the functional loading of a crown with a cemented post and core creates stresses in the prosthesis and the root. If these stresses exceed the yield strength of the materials, fracture of the restorative materials or the tooth may occur. Frequent loading may cause strains and stresses in the cement layer that could result in damage to the cement layer, leading to restoration debonding.[6]

The simultaneous interaction of the many variables affecting a restorative system can be studied using a simulation in a computerized model. The finite element analysis (FEA) consists of dividing a geometric model into a finite number of elements, each with specific physical properties. The variables of interest are approximated with some mathematical functions. Stress distributions, in response to different loading conditions, can be simulated with the aid of computers with dedicated software.[20] The stresses that are generated may be tensile, compressive, shear or a combination thereof, known as equivalent Von Mises stresses. Von Mises stresses depend on the entire stress field and are a widely used indicator for the possibility of damage occurring.[21]

There are several studies in the literature that present the biomechanical behavior of restored teeth with post and crown restorations. However, post systems associated with direct composite restorations have not been largely evaluated.[22] The current study evaluated the influence of two different post systems and the elastic modulus and film thickness of resin cement on the stress distribution of a fractured MCI restored with resin composite by direct technique using FEA. The null hypothesis was that these parameters would not result in great changes in the stress induced in the tooth-restoration complex.

METHODS AND MATERIALS

A model of an MCI with a coronary fracture and supporting structures was modeled from pictures in textbooks.[23-25] Pre-fabricated posts and resin composite restorations were also modeled. These pictures were scanned into digital images to determine a proportional relationship between the drawings of the buccal, palatal and proximal faces. The cross-sectional drawings were created with a 1.5 mm distance between each image. These drawings were used to draw the model outline on scaled paper. The outline of the model was then digitized into the computer. The FEA was performed with the FE software program (ANSYS rel 5.2, Ansys Inc, Houston, TX, USA). The study model presented the configurations and dimensions presented in Figure 1.

Eight experimental models, with their variables investigated (different post materials, elastic moduli and film thickness of resin cement), were prepared as reported in Table 1. The elastic constants used in the calculations were obtained from the literature (Table 2).[26-33] With the exception of the GF post, the materials were assumed to be isotropic. GF posts were considered orthotropic, as they are made up of long fibers (glass fibers) embedded into a polymeric matrix, with different mechanical properties along the fiber direction (x direction) and along the other two normal directions (y and z direction). The mechanical characteristics of the GF post are reported in Table 3.[30] E_x, E_y and E_z represent the elastic moduli

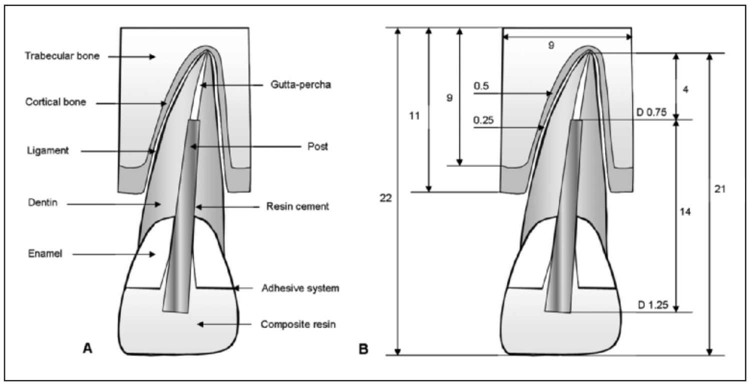

Figure 1. *(A) Materials and components involved in the investigated model; (B) dimensions (mm) of investigated model and post diameters (D).*

along the three dimensional directions, while v_{xy}, v_{xz} and v_{yz} and G_{xy}, G_{xz} and G_{yz} are the Poisson's ratios and the shear moduli in the orthogonal planes (xy, xz and yz, respectively). The study elements were defined as described. The Solid92 element was used for enamel, dentin, cortical bone, medullar bone, gutta-percha, posts and resin composite (the solid corpus), with 10 nodes and three degrees of freedom per node. The Shell63 element was used for the resin cements, adhesive system and periodontal ligament (the laminate corpus), with four nodes and six degrees of freedom per node. The adhesive system and periodontal ligament presented thicknesses of 10 µm and 250 µm, respectively.[28,32]

The following assumptions were made: there is complete bonding between the post and cement; dentin was assumed to contain elastic isotropic material[30] and the cementum and dentin were considered to be a single structure. The volumes were meshed, finally resulting in a 3-D FE model with 109,141 elements and 133,681 nodes. All of the nodes on the external bone surface were constrained in all directions. A linear static structural analysis was performed to calculate the stress distribution in the post, cement layer and dentin, under a chewing static pressure of 2.16 N/mm^2 applied at the palatal surface in two areas of the resin composite. This pressure produced a force of 10 N in the "z" direction, producing model flexion, and another force of 8 N in the "y" direction, producing model compression. Accuracy of the model was checked using convergence tests. Particular attention was given to the refinement of the mesh resulting from the convergence tests at the cement layer interfaces. The results are presented in terms of Von Mises stress values, because a higher Von Mises stress is a strong indication of a greater possibility of failure.

Table 1: *Experimental Models*

Model	Post Materials	Cement	
		Elastic Modulus (GPa)	Film Thickness (µm)
Model 1	GF	7.0	70
Model 2	GF	18.6	70
Model 3	GF	7.0	200
Model 4	GF	18.6	200
Model 5	ZC	7.0	70
Model 6	ZC	18.6	70
Model 7	ZC	7.0	200
Model 8	ZC	18.6	200

Table 2: *Materials Properties in FEA Models*

Material/Component	Elastic Modulus (GPa)	Poisson's Ratio (v)	Reference
Dentin	15	0.31	26
Enamel	80	0.30	26
Periodontal Ligament	0.05	0.49	28
Compact Bone	13.8	0.26	28
Medullar Bone	0.345	0.30	27
Resin Composite	12.5	0.30	29
Adhesive System	4.5*	0.30**	*32 **29
Gutta-percha	0.1	0.49	31
Resin Cement (low modulus)	7	0.28	31
Resin Cement (high modulus)	18.6	0.28	31
Zirconia Ceramic	205	0.31	33

RESULTS

When the 3-D models of MCI were subjected to simulated masticatory loading, a qualitative analysis of the stress distribution was observed in the post, cement layer and dentin by figures and cores represented as Von Mises stresses.

Effect of the Post

The maximum stress in the ZC post models occurred in the posts, concentrated between the medium and apical portions of the posts, regardless of the cement conditions. However, the post in the GF post models showed a more homogeneous stress distribution with very small values (Figure 2). Slightly higher stresses in the ZC post models (Figure 3) occurred in the cement layer. However, slightly higher stresses in the GF post models occurred in dentin, concentrated on the coronal third of the root facial surface (Figure 4).

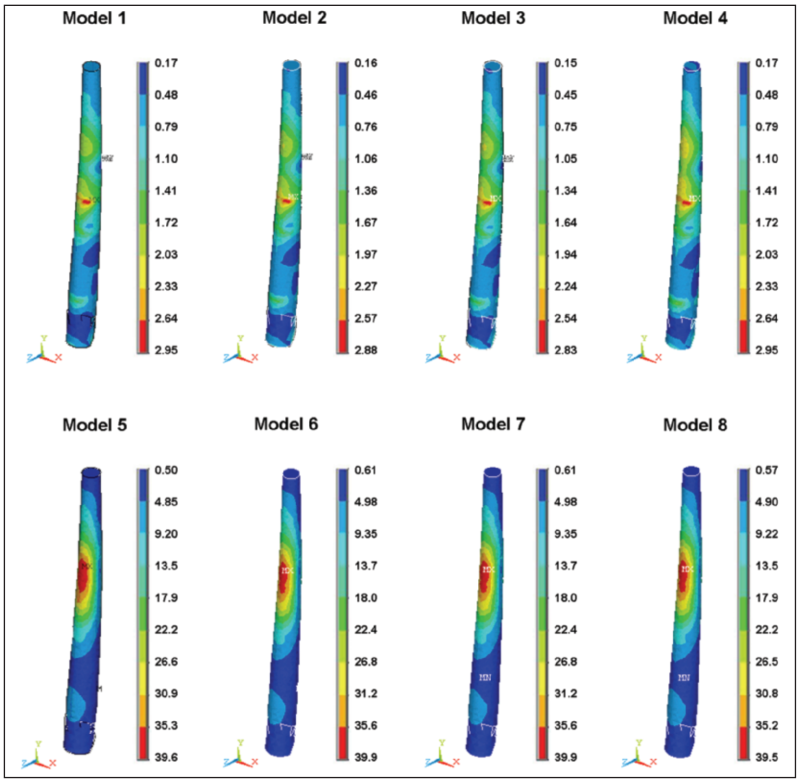

Figure 2. *Qualitative analysis of the stress distribution (in MPa) for the post in the different experimental models using figures and core gradients of the Von Mises stresses.*

Effect of the Resin Cement

The elastic modulus and film thickness of the resin cement did not show significant changes in the distribution of stresses in the post and dentin. However, a vast increase in stress levels in the cement layer was created when using the higher elastic modulus cement, regardless of the post used (Figure 4). The film thickness of the cement layer showed few changes in stress levels, but the maximum stress zones became more evident with the 200 µm thickness.

DISCUSSION

FEA has been widely used in dentistry. When this method is compared with laboratory testing, it offers several advantages. The variables can be changed easily, the simulation can be performed without the need for human material and it offers maximum standardization.[18] Several recent studies[18-21,30,34-35] analyzed 3-D stress distribution using the FEA method with endodontically-treated teeth restored with post and core, which were associated with the indirect crown placement technique. The 3-D FEA method was shown to be a useful tool when investigating complex systems. MCIs protect posterior teeth during protrusive movement, making posterior teeth disocclude. Moreover, the stresses that arise during tearing in these teeth are of paramount importance for the long-term success of a restoration.[34] MCI was selected for its ability to subject the specimens to oblique occlusal stresses. All FE models contained a periodontal ligament and cortical and medullar bone, since it has been suggested that the periodontal ligament and alveolar bone should be considered in the FEA of teeth.[36] The load was applied in two areas to try and simulate the clinical force of mastication.[37]

Table 3: *Orthotropic Properties of the GF Post*

Property	GF Post
E_x (GPa)	37
E_y (GPa)	9.5
E_z (GPa)	9.5
v_{xy}	0.27
v_{xz}	0.34
v_{yz}	0.27
G_{xy}	3.1
G_{xz}	3.5
G_{yz}	3.1

The placement of an endodontic post creates an unnaturally restored structure, since the root canal space is filled with a material that is unlike pulp with regard to stiffness. Stress distribution is more uniform in a sound tooth.[30,34] However, the physiological differences between cementum and enamel cause the produced stress to be concentrated in the cervical region, as a non-homogeneous distribution material causes the stress concentration.[34] Consequently, the interface of materials with different elastic moduli represent the weakest point of a restorative system.[8,38] The figures presented in the current study represent the post, cement layer and dentin. The investigated model parts were separated for more accurate structure analysis.

For some study parameters, the FEA showed considerable changes in the stresses induced in the tooth-restoration complex. Thus, the null hypothesis that variation of the parameters would not influence stress distribution was partially rejected. ZC posts created slightly less stress at the external dentin surface, receiving more stresses in the post. The greater stress for the GF post models at the external dentin surface results from the flexibility of the post and the presence of a less stiff core material.[18,34] In a 2-D FE study, Pegoretti and others[39] concluded that the GF post resulted in lower stresses "inside the root" compared to the stresses created by other post systems with higher elastic moduli. However, those authors fail to mention that these stresses were not found in dentin. Instead, they were found within the post itself.[21]

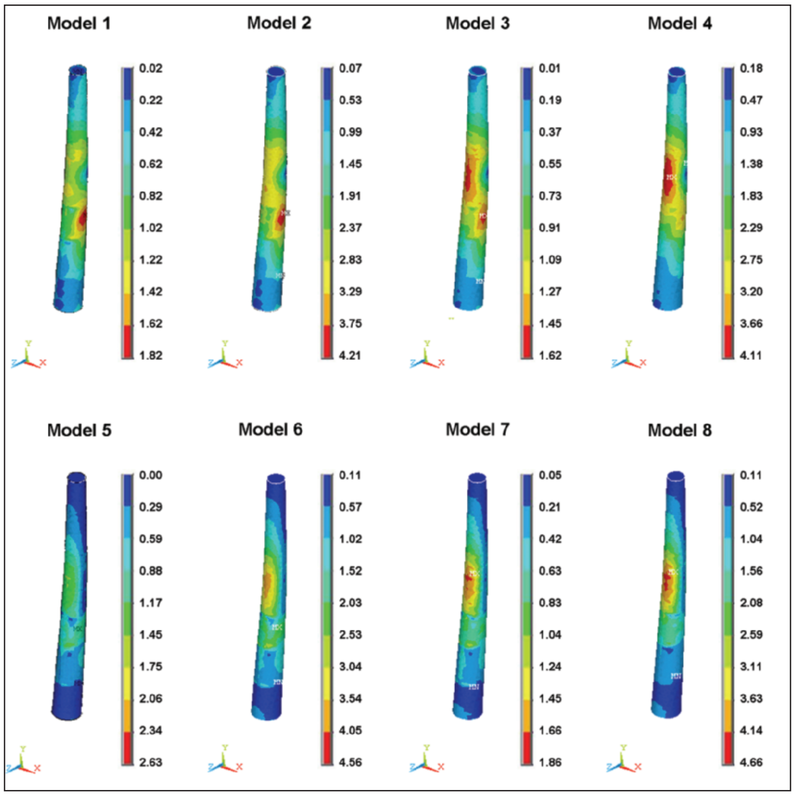

Figure 3. *Qualitative analysis of the stress distribution (in MPa) for the cement layer in the different experimental models using figures and core gradients of the Von Mises stresses.*

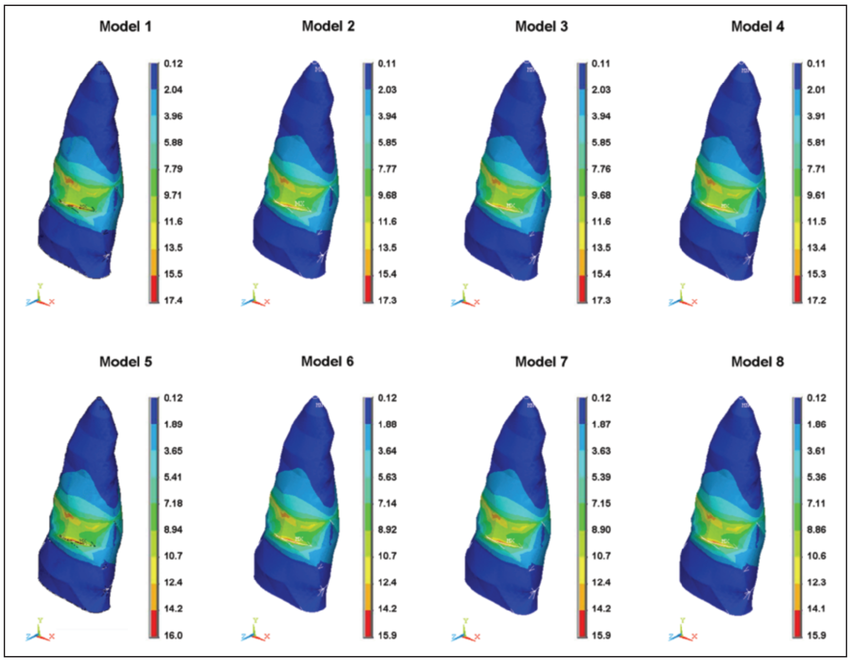

Figure 4. *Qualitative analysis of the stress distribution (in MPa) for the dentin in the different experimental models using figures and core gradients of the Von Mises stresses.*

Ceramic posts are stronger than prefabricated metal and fiber posts, but they have a lower resistance to crack propagation.[40] This fact, which is associated with high stress concentration in the ZC post, might explain the post fractures without root fractures.[41] This can be explained as the energy being absorbed by the post, thus reducing the stress created in dentin. Additionally, the fact that a post fracture can occur prior to reaching the proportional limit characterizing a friable material is worth noting.[17] Some authors state that fracture of a ZC post can result in tooth loss, because it is nearly impossible to remove the apically-fixed part of the broken post.[42-43] Failures of GF post systems also are normally due to post fracture,[41] but these posts are easier to remove without the risk of perforating the root, because a bur can be used to remove the remaining post piece.[44]

The results from the current study show that the resin cement elastic modulus and thickness did not create significant changes in stress distribution for the post and dentin. However, resin cement with a high elastic modulus had a considerable increase on stress in the cement layer, regardless of the post used, thus increasing the risk of debonding. When using ceramic crowns, Lanza and others[30] concluded that the rigidity of the cement layer is less relevant to the GF post when compared with the carbon fiber post. This difference between studies can be explained by the fact that restorations with a direct resin composite, as prepared in the current study, can transmit the load directly to the post and cement layer with a lower maximum stress to cement with a low elastic modulus.

The cement layer thickness is less relevant on stress distribution, but film thicknesses greater than 200-µm should be avoided due to a tendency to develop maximum stress zones. When evaluating using dislocation resistance, D'Arcangelo and others[45] showed that thicknesses of 100 µm or 120 µm presented better results than either greater or lesser thicknesses. Grandini and others[46] evaluated resin cement thickness after luting anatomic and standardized fiber posts into root canal preparations. These authors suggested that the cement layer that is produced with ill-fitting posts is too thick, with bubbles likely to be present, predisposing the post to debonding. The formation of bubbles or voids, representing areas of weakness within the material, is less likely to occur in a thin, uniform layer of cement. Moreover, the polymerization stress that develops within a relatively thin thickness of cement would be minimal.[46]

GF posts are compatible with the Bis-GMA resin used in bonding procedures; therefore, they can be bonded in the root canal with resin cement and adhesive systems. These bonding agents transmit stress between the post and root structure, reducing stress concentration and preventing fracture.[30] Bonding between post-cement and cement-dentin appears to be an important parameter in achieving an optimal biomechanical behavior of endodontic restorations.[30] Grandini and others[22] related that, after a 30-month clinical evaluation, teeth restored with fiber posts and restorations using direct resin composite, exhibited favorable clinical results. The results and findings in the dental literature and the current study suggest that GF posts and resin cement with an elastic modulus less than dentin should be preferred in restorations of this type. Further studies addressing the role of the thickness of the cement layer and the use of a resin composite without a post must be conducted.

CONCLUSIONS

Within the limitations of this theoretical study, the following conclusions were drawn:

1. The stiffness of the post and resin cement had a considerable effect on the stress distribution in an MCI restored with resin composite using the direct technique.
2. The use of a glass fiber post associated with a resin cement having an elastic modulus less that of dentin should be preferred in restorations of this type, because of the lower concentration of stresses in the post and cement, decreasing the risk of fracture and debonding of the post.
3. The cement layer film thicknesses showed little influence on stress distribution.

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