©*Operative Dentistry, 2006,* **31-1**, 47-54

Influence of Prefabricated Post Material on Restored Teeth: Fracture Strength and Stress Distribution

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Clinical Relevance

When restoring teeth, a higher restoring success rate can be achieved by using posts with an elastic modulus similar to that of dentin and a core, with equal or higher strength, such as glass fiber posts. Moreover, the failure mode for these post systems will allow for further repair.

SUMMARY

Aims

This work studied how prefabricated intraradicular post material affects the mechanical performance of restored teeth. The effect of using two different materials (glass fiber and stainless steel) with significantly different elastic moduli was studied.

Methods

A combined theoretical and experimental method was used: first, an experimental fracture strength test was performed on 60 extracted human maxillary central incisors. The teeth were decoronated, treated endodontically and restored, 30 with glass fiber posts and 30 with stainless steel posts. The data were recorded and the results compared using an ANOVA test.

Then, the finite element technique was used to develop a model of the restored tooth. For both post systems, the model allowed for the study of stress distribution patterns on the restored tooth under external loads.

Results

For teeth restored with stainless steel posts, a significantly lower failure load was found, as compared with those teeth restored with glass fiber posts (520 N versus 803 N). The estimated

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DOI: 10.2341/04-169

distributions confirmed a worse mechanical performance on teeth restored using stainless steel posts, with a high stress concentration due to the significant difference between the elastic moduli of the steel and the surrounding materials.

Conclusion

Within the limitations of this study, post systems, where the elastic modulus of the post is similar to that of dentin and core, have a better biomechanical performance.

INTRODUCTION

Dentistry has undergone a significant evolution since its beginnings. Many technological advances have taken place since the first extracting theories. Today, the tendency is to keep any tooth, even if only a small piece remains. This is possible because of advances in endodontics, which allow the tooth to be kept once it is devitalized, and advances in restorative dentistry, with its modern restoring techniques (Qualtrough & Mannocci, 2003). Devitalized teeth usually present important biomechanical shortcomings, such as the loss of dental substance, due to caries or previous restorations (Walton & Torabinejad, 2002). In order to restore devitalized teeth, modern restoring techniques use an external element—the intraradicular post—as a retention system for the material used in the tooth restoration, which is carried out later. These posts primarily retain the crown, supporting the final restoration. The post has been proven to not reinforce the endodontically treated tooth; instead, it can weaken it (Milot & Stein, 1992), contradicting what was thought to be true in the past.

Many different kinds of posts have been described in the literature (Fernandes, Shetty & Coutinho, 2003). At first, cast metal alloy posts and prefabricated posts made of stainless steel, titanium or precious alloys were used. The cast post core system is more time consuming and entails an intermediate laboratory phase to elaborate the retaining system, making the procedure more expensive. Prefabricated posts do not require this intermediate phase and, therefore, allow the whole restoration to be performed in one visit, resulting in an easier, less expensive technique. However, adaptation of the post to the root canal may be less accurate (Chan, Harcourt & Brockhurst, 1993).

Some confusion or disparity of results concerning how the post material affects the resistance performance of restored teeth has been observed in the literature (Fernández, Méndez & Torassa, 2002). Some studies claim that metallic posts perform better than fiber posts (Martínez-Insúa & others, 1998; Ludi & others, 1998); others, however, state the opposite (Isidor, Odman & Brondum, 1996; Ferrari & others, 2000a; Dietschi, Romelli & Goretti, 1996; Mannocci, Ferrari & Watson, 1999). Recently, the influence of the material on cast post core systems (Eskitascioglu, Belli & Kalkan, 2002) has been studied. While the results from a finite element model estimated better performance for metal, the results from a fracture strength test did not corroborate this finding. Nevertheless, today, it is commonly accepted that better performance is achieved if the stiffness of the post's material is similar to that of dentin (Fernandes & Dessai, 2002).

In order to clarify the apparent confusion of results found in the literature, the current research studied the influence of the material used to manufacture prefabricated intraradicular posts on the resistance performance of restored teeth. An experimental fracture strength test was performed on extracted human teeth that were restored using two different post materials, and a 3D finite element model of the restored tooth was then used to analyze the stresses that originated with the different post materials.

METHODS AND MATERIALS

Two different post materials were selected for the study: glass fiber and stainless steel. The posts selected were the ParaPost Fiber White and the ParaPost Stainless Steel (Coltène/Whaledent Inc, Mahwah, NJ, USA). The geometry of both posts is similar, and they are manufactured in the same sizes, although the elastic moduli of both posts are significantly different (20-30 GPa for the ParaPost Fiber White and 207 GPa for the Parapost Stainless Steel).

This research studied how the post material affects the mechanical performance of teeth that need a restoration. A combined theoretical and experimental method was used. In the first study, an experimental fracture strength test was performed on endodontically treated and restored teeth. This test analyzed the differences in strength between the two intraradicular post systems. In the second study, the finite element technique was used to develop a 3D model of the restored tooth. This model allowed the authors to study the stress distribution pattern of the restored tooth under external loads for both post systems. The stress distribution pattern provided information about the fracture mechanism of the restored tooth. Finally, the results from the fracture strength test were used to check the validity of the finite element model and the results from the simulations.

Fracture Strength Test

The goal of the fracture strength test was to analyze how much the selected prefabricated post material affected the final biomechanical performance of the teeth. Sixty human maxillary central incisors without fractures or cracks, which had been extracted for periodontal reasons, were selected for this study. Thirty specimens were restored using glass fiber posts and 30 specimens were restored using stainless steel posts. No control group of unrestored teeth had been considered, because the purpose was not to determine whether restoring teeth using prefabricated posts was more suitable than other techniques, but merely to compare how the prefabricated post material affected the final mechanical performance of teeth needing a restoration, assuming that prefabricated posts are to be used.

To prevent moisture loss from the root structure, the teeth were preserved in humidity saturation conditions until used. The same operator performed the endodontic treatment and restoration for all specimens. The teeth were decoronated, leaving only the root. The coronal and medial root canal regions were prepared using sizes 1 through 3 Gates Glidden drills (Mani Inc, Tachigi-ken, Japan). The step-back technique was used for the remainder of the canal, and #30 K-type files (Dentsply-Maillefer, York, PA, USA) were used. The specimens were obturated with gutta-percha by using the lateral condensation technique and AH Plus sealer (Dentsply-Maillefer).

After endodontic treatment, the teeth were embedded in individual auto-polymerizing acrylic-resin blocks via a mold; 1.5 mm of the root was left unsubmerged to simulate the real conditions of inclusion of teeth into the bone. Twenty-four hours later, the posts were inserted and cemented, with the resin cement ParaPost Cement (Coltène/Whaledent Inc), in compliance with the manufacturer's instructions. Thirty specimens were restored using glass fiber posts and 30 specimens were restored with stainless steel posts. To standardize the size and length of the posts, the recommendations from the literature (Fernandes & Dessai, 2002) were followed; that is, the post length used was three-quarters of the root length of each specimen, and the post size that was used was smaller than one-third of the root diameter, but as close as possible to this value. The later restoration of the crown was performed with the dual cure resin ParaCore (Coltène/Whaledent Inc), in compliance with the manufacturer's instructions. Twenty-four hours later, the core was finished with a high-speed diamond bur as if a porcelain-fused-to-metal full-coverage crown was placed. The teeth were tested without the final crown restoration being made and cemented, because the less ideal situation was selected for the experiment; that is, the entire external load was transmitted to the core. Inclusion of the final crown would have transmitted part of the load directly to the root.

An IBERTEST ELIB-30/W (Ibertest, Madrid, Spain) universal testing machine was used for the experiment. The specimens were placed in a retention device and mounted on the universal testing machine that allowed the teeth to be loaded on the palatal side at a 30° angle to the radicular axis in the vestibular direction (Figure 1), simulating the real direction of loads during biting (Korioth & others, 1997). A controlled loading force was applied to the teeth at a rate of 5 N/s until failure. The loading force (N) required to cause failure was recorded, and the results for the groups were compared using an ANOVA test.

Finite Element Model

The finite element technique is currently used in very different fields. It has been successfully used in biomechanics and, in particular, in orthopedics. This technique was originally developed for structural analysis in mechanical engineering, but its foundation is also applicable to biological problems. This method consists of dividing the system to be studied into a set of small, discrete elements (finite elements) defined by nodes. A stiffness matrix is defined for each element, depending on its geometry and material and is expressed in terms of the nodal forces and displacements. By forcing the nodes shared by adjacent elements to have the same displacements, the element stiffness matrices are combined to give the global stiffness matrix. Nodal displacements are obtained using the boundary conditions and given loads, and the strains and stresses are then calculated from them. As the size of the elements decreases (increasing the number of elements), the accuracy of the method increases, but the computational cost also rises significantly.

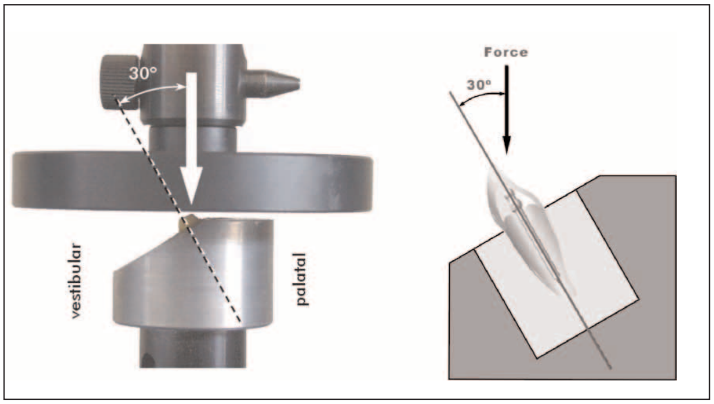

Figure 1: *Experimental fracture strength test performed on teeth.*

Table 1: *Mean Values and Standard Deviations of the Measurements Taken Over 40 Root Specimens for Generating the Model Geometry*

		Mean (mm)	Standard Deviation (mm)
Cervico-apical height		14.0	2.8
Mesio-distal diameter	At cervical height	5.5	0.8
	At medial height	4.0	0.6
Vestibulo-palatal diameter	At cervical height	7.2	1.0
	At medial height	5.5	0.7

Figure 2a: *Longitudinal section of an endodontically treated and restored tooth.*

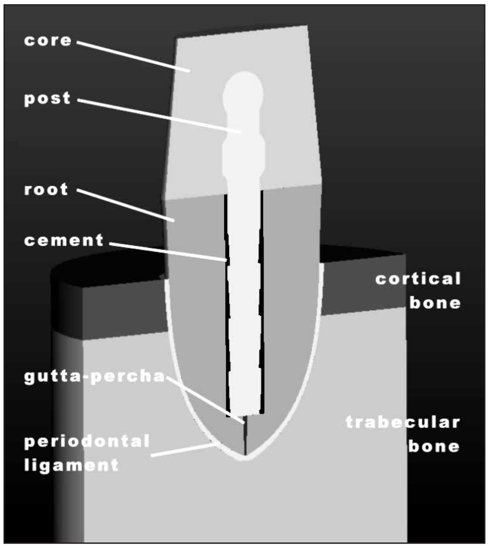

Figure 2b: *Section of the geometrical model generated. Components modeled.*

Figure 3: Mesh considered for the post.

Every finite element model is generated by dividing (meshing) a given geometry previously constructed by using CAD software. In this work, the 3D modeling software Pro/Engineer (PTC, Needham, MA, USA) was used to generate and later assemble the geometries for all the components that represent the endodontically treated and restored tooth. To generate the geometry, measurements were taken from 40 extracted human maxillary central incisors: the cervico-apical height and mesio-distal and vestibulo-palatal diameters at both cervical and medial root heights were recorded. The mean values from these measurements define the geometry of the tooth used in this study (Table 1). A longitudinal section of an endodontically treated and restored tooth was used to define the configuration of the different elements in the model (Figure 2a). Figure 2b shows a longitudinal section of the geometrical model considered, including all the components that were modeled: bone (cortical and trabecular components), periodontal ligament, root/dentin, gutta-percha, post, cement and core.

The Pro/Mechanica module, available within Pro/Engineer, was used for dividing (meshing) the CAD geometry. Solid tetrahedral elements were used for the mesh, and ideal adherence was assumed between adjacent components; that is, nodes from adjacent elements belonging to different components were shared to ensure continuity. The size of the elements generated varied depending on the different geometries that were meshed, so that the final mesh accurately represented the original geometry (Figure 3). The model had a total of 482,000 elements defined by 86,300 nodes.

The mechanical properties of the different components of the model were obtained from the literature (Eskitascioglu & others, 2002) and from the posts' manufacturer (Coltène/Whaledent Inc). The properties mentioned are presented in Table 2. The elastic modulus "E" quantifies the response of a material to elastic or springy deflection—it is a measure of stiffness. Materials with higher elastic modulus are less deflectable. Poisson's ratio "v" is the ratio of transverse contraction strain to longitudinal extension strain. As boundary conditions, displacement of all nodes on the lateral surface and base of the cylinder that represent the bone were constrained. Normal chewing forces were in the range 10-50 N (Bosman, 1995), but much higher force peaks can occur *in vivo* (Körber & Ludwig, 1983; Pröschel & Morneburg, 2002). Maximum biting forces between 500 and 600 N and, sometimes force peaks up to 1000 N, were reported (Ludwig, 1975; Pröschel & others, 1994; Tate & others, 1994; Kleinfelder & Ludwigt, 2002). In order to carry out a clinically relevant study, the authors considered a 300 N load on the palatal side of the tooth at an angle of 30° to the radicular axis in the vestibular direction to simulate real biting force.

Two static structural analyses were performed using the finite element analysis software MSC-PATRAN-NASTRAN (MSC.Software Corporation, Santa Ana, CA, USA), one for the tooth restored with a glass fiber post and the other for the restoration performed using the stainless steel post.

RESULTS

Results From the Experiment

From the ANOVA analysis, significant differences were observed between the failure loads of teeth restored using stainless steel posts and those teeth restored using glass fiber posts ($p<0.05$) (Table 3). The failure loads for the teeth restored with stainless steel posts were significantly lower than the failure loads for teeth restored with glass fiber posts (519.93 N versus 803.44 N, respectively). Box-whisker graphs showing spreads of values in both data sets can be observed in Figure 4.

Table 2: *Mechanical Properties of the Materials Used in the Finite Element Model*

Component/Material	Behavior	Elastic Modulus E (GPa)	Poisson Coefficient v
Root/Dentin*	Isotropic	18.6	0.31
Gutta-percha**	Isotropic	0.00069	0.45
Periodontal ligament*	Isotropic	0.0689	0.45
Cortical bone*	Isotropic	13.7	0.30
Trabecular bone*	Isotropic	1.37	0.30
Cement**	Isotropic	18.6	0.30
Core**	Isotropic	20	0.30
Post/Steel**	Isotropic	207	0.30
		E_1 $E_2 = E_3$	$V_{21} = V_{31}$ V_{32}
Post/Glass Fibre**	Transversally Isotropic	30 20	0.3 0.3

**From Eskitascioglu, Belli & Kalkan, 2002*
***From the manufacturer Coltène/Whaledent Inc, Mahway, NJ, USA*

Table 3: *Results From the ANOVA Analysis of the Failure Loads for Both Groups of Specimens Studied*

Groups	Count	Sum (N)	Mean (N)	Variance (N²)
Steel	30	15598	519.93	66896.37
Glass Fibre	30	24103.2	803.44	42141.18

Source of Variances	Sum of Squares	Degrees of Freedom	Mean of Squares (N²)	F	Probability (p)	Critical Value for F
Between groups	1205640.45	1	1205640.45	22.114	1.6308E-05	4.007
Within the groups	3162088.92	58	54518.77			
Total	4367729.37	59				

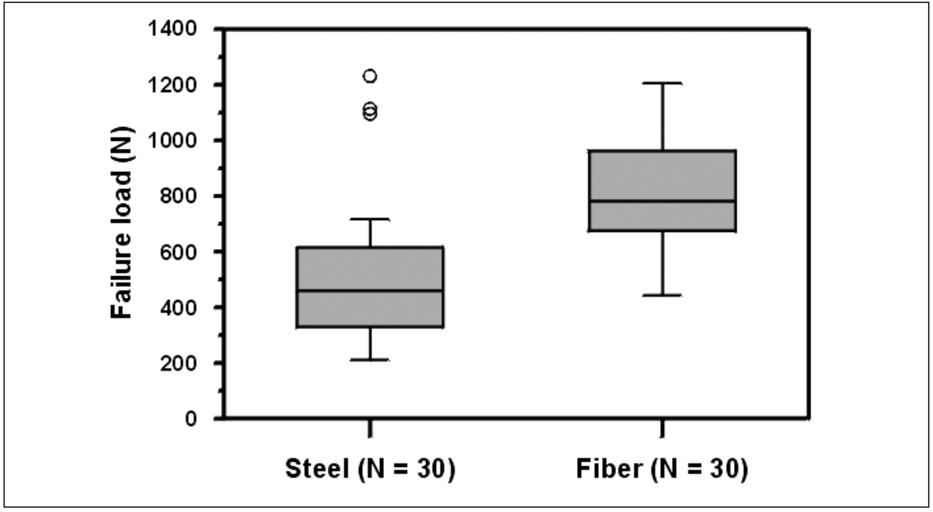

Figure 4: Box-whisker graphs showing spreads of failure load values for both groups of studied specimens.

The mode of failure of the restored teeth was also different in each of the two post systems (Figure 5a). Teeth restored using glass fiber posts showed a fracture of the core at the juncture with the dentin on the vestibular side (Figure 6a). This is due to the tooth bending, which caused higher stress concentration on this side. Conversely, teeth restored using stainless steel posts showed a fracture of the core along the juncture with the post on the vestibular side as well (Figure 6b).

Results From the Model

The Von Mises stresses, which estimated using the model for each point of the central longitudinal section of the restored tooth, are represented in Figure 5b and use a color scale (warmer colors represent higher stresses). The model predicted significantly different stress distribution patterns for both post systems. Glass fiber post systems had lower stress values compared with stainless steel post systems. For the tooth restored with a glass fiber post, no stress concentrations were observed on the model. Maximum stresses of 90 MPa were estimated at the vestibular embedding region of the tooth into the bone within the dentin and the composite core. For the tooth restored using a stainless steel post, the model predicted a stress concentration at the post-core-cement interface, with stresses close to 190 MPa. This stress concentration was due to the difference in stiffness of the post with respect to its surrounding material (core, cement and dentin). For both post systems, the different stress distribution patterns over the composite core are clearly visible in Figure 5c.

DISCUSSION

In order to compare the mechanical performance of different post systems, many studies have been performed (Dietschi & others, 1996; Isidor & others, 1996; Ludi & others, 1998; Martínez-Insúa & others, 1998; Mannocci & others, 1999; Ferrari & others, 2000a; Akkayan & Gülmez, 2002; Eskitascioglu & others, 2002; Fernandes & Dessai, 2002), yielding opposite findings in some cases. As a result, some confusion has been observed in the literature (Fernández & others, 2002) regarding how post material affects the resistance performance of restored teeth.

This study compared the fracture strength, mode of failure and stress distribution of teeth restored with two different post systems: ParaPost Fiber White and Parapost Stainless Steel. Natural teeth were used to prepare the specimens. All roots received endodontic treatment and care was taken to fabricate standard cores. The posts selected had a very similar geometry and were manufactured in the same sizes. To standardize the size and length of the posts, recommendations from the literature (Fernandes & Dessai, 2002) were followed. The elastic moduli of both posts were significantly different. The teeth were loaded until failure on the palatal side at a 30° angle to the radicular axis in the vestibular direction, thus simulating the real direction of loads during biting (Korioth & others, 1997). This procedure enabled the authors to assert that differences in the experimental results were a consequence of the only different parameter between the teeth restored in the study—the post material.

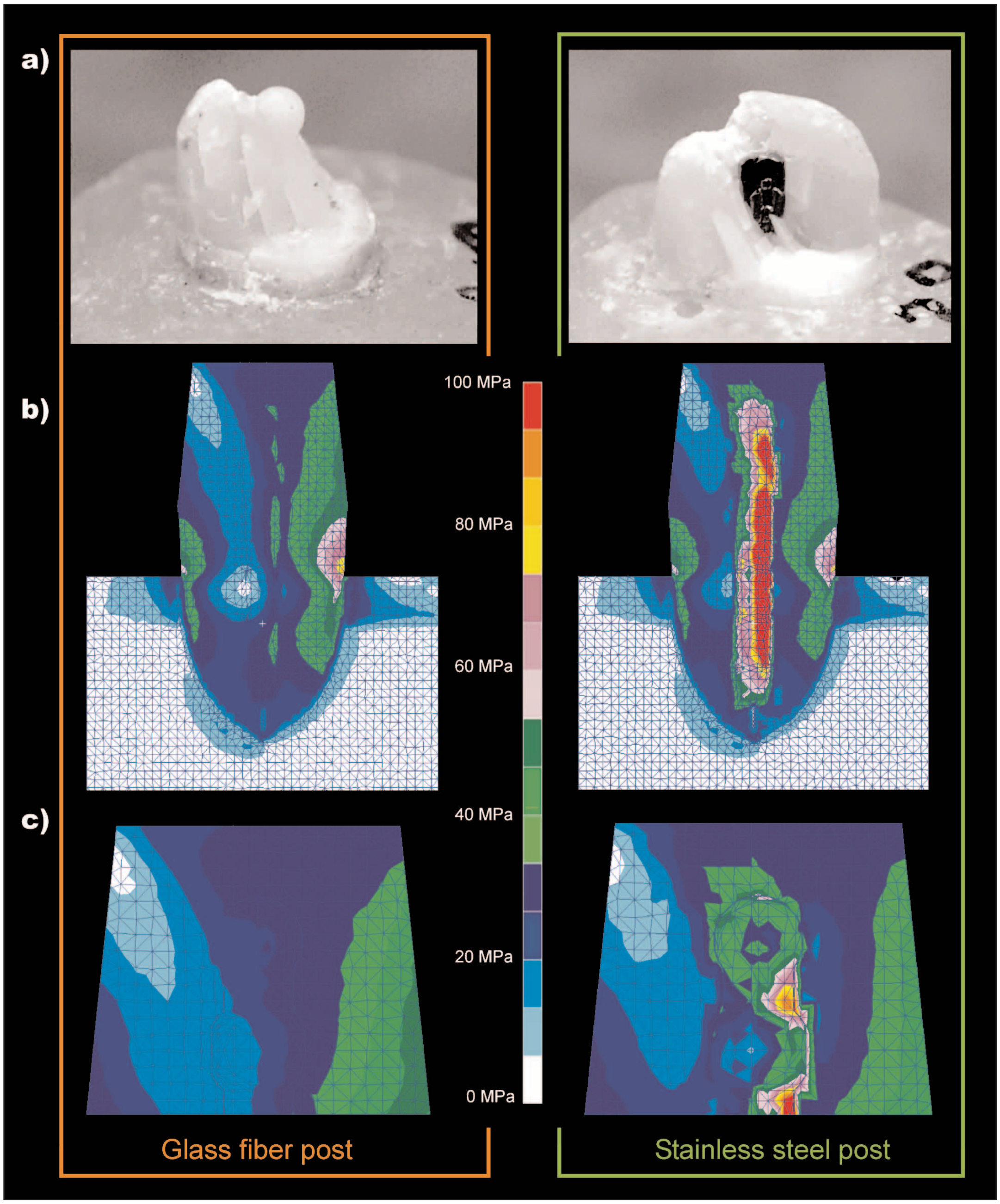

Figure 5: *Results: a) detail of the experimental fractures on the restored teeth; b) estimated Von Mises stress distribution patterns; c) detail of the estimated Von Mises stress distribution patterns on the composite core.*

A better biomechanical performance has been experimentally observed for the glass fiber posts, with greater fracture loads and with a mode of failure allowing for repair, because the root was not affected by fracture. The developed model also predicted a different biomechanical performance between the use of stainless steel and glass fiber posts for restoring teeth. For the stainless steel posts, a stress concentration was predicted along the interface of the post with the composite core. This stress concentration did not appear in the case of glass fiber posts. These differences in the estimated

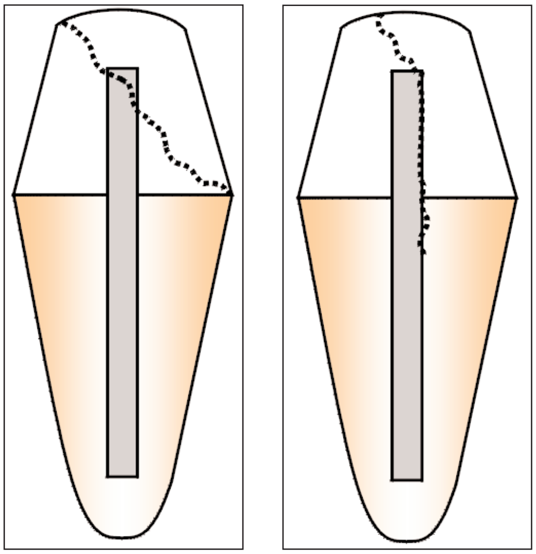

Figure 6: *Modes of failure for both post systems studied: a) glass fiber post system; b) stainless steel post system.*

stress distribution patterns obtained from the model agreed with the experimental fracture modes observed: the higher estimated stresses at the post-core interface for teeth restored with stainless steel posts induced fractures along the post (Figure 6b); the higher stresses at the juncture with dentin (on the vestibular side) for teeth restored with the glass fiber post induced a fracture of the core beginning at that juncture (Figure 6a). Moreover, the lower experimental fracture loads obtained for the stainless steel post systems agreed with the higher stresses estimated by the model for that system. The predictions obtained from the finite element model were, therefore, corroborated by the experimental results, thus validating the model.

The static failure loads obtained from the experiment for both material posts are greater than routine biting loads (Bosman, 1995; Korioth & others, 1997). Nevertheless, it is important to not forget the fatigue effect of real loads. The smaller static failure load for steel post systems will result in a shorter life of the tooth restoration, which is clinically relevant. In addition, the failure mode for teeth restored using glass fiber posts does not affect the root, but only the core. Thus, after a hypothetical failure, a further restoration is still possible if glass fiber posts are used.

The results from the simulations performed with the finite element model allowed the authors to identify the difference in the elastic moduli between the post and dentin and core as the origin of stress concentrations at the post-core-cement interface that weakened the restored tooth, despite introducing a stronger post. The results from the fracture strength test confirmed this finding, with the stainless steel post clearly displaying worse performance than the glass fiber post. This finding is also corroborated by other experimental results from the literature. Isidor and Ferrari's studies (Isidor & others, 1996; Ferrari, Vichi & García-Godoy, 2000b) emphasized the better biomechanical performance of carbon fiber versus steel. In this case, carbon fiber was the material with an elastic modulus that was most similar to dentin, which meant that the assembly had a more favorable performance with a lower failure rate. The results obtained by Dietschi (Dietschi & others, 1996) in his fatigue studies and the *in vitro* results obtained by Mannocci (Mannocci & others, 1999) corroborate the findings of this work as well, with zirconium posts showing a lower success rate than fiber posts (zirconium elastic modulus is 200 GPa). In the same way, Akkayan and Gülmez (2002) observed fractures allowing repair for glass and quartz fiber post systems and for non-restorable fractures for zirconium and titanium post systems. The works that stated a better performance for metallic posts (Martínez-Insúa & others, 1998; Ludi & others, 1998) did not compare two prefabricated post systems; they actually compared cast post core systems with prefabricated post systems. Therefore, within the limitations of this study, it can be postulated that research into new materials should focus on those systems with an elastic modulus close to dentin with a strength equal to or higher than dentin. In this sense, glass fiber posts make a very interesting choice for post-endodontic restoration, because of their three main attributes: good biomechanical performance because post, core, cement and dentin constitute a homogeneous ensemble; excellent aesthetics, which makes them suitable for restorations in the anterior region; and good adhesion to cement agents.

The experimental results obtained from the fracture strength test corroborated the estimations from the model, thus validating the model that was developed. The proposed model could be a useful tool for studying the influence that different post design variables have on the biomechanical performance of restored teeth by means of simulations. Hence, future research should focus on how the length, size and design of the post, the cementing technique or the post insertion parameters influence the biomechanics of restored teeth. The crossed influence between these parameters should be studied as well in order to analyze, for example, which material provides a less sensitive biomechanical performance to the length or size of the post, thus ensuring a more robust restoration technique. These analyses will allow data that can help to reduce post-treatment iatrogenic lesions that are obtained.

CONCLUSIONS

Within the limitations of this study, it has been experimentally proven that the stainless steel post had a worse performance than the glass fiber post, with failure loads significantly lower for teeth that were restored with the stainless steel post. Moreover, the failure mode of glass fiber posts allows for further repair.

The experimental results corroborated the estimations from the developed model, thus validating the model. The proposed model could be a useful tool for studying the influence that different post design variables have on the biomechanical performance of restored teeth, by means of simulations.

(Received 17 September 2004)

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