International Endodontic Journal

doi:10.1111/j.1365-2591.2010.01782.x

Biomechanical behaviour of a fractured maxillary incisor restored with direct composite resin only or with different post systems

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Abstract

Garbin CA, Spazzin AO, Meira-Júnior AD, Loretto SC, Lyra AMVC, Braz R. Biomechanical behaviour of a fractured maxillary incisor restored with direct composite resin only or with different post systems. *International Endodontic Journal*, **43**, 1098–1107.

Aim To compare stress distribution between a fractured maxillary central incisor restored with direct composite resin only (CR) or associated with different post materials, using finite element analysis.

Methodology A three-dimensional model of a sound maxillary central incisor and supporting structures was constructed, using data from the dental literature. Changes were made in the crown region to create a tooth with a restored crown fracture. A composite resin restoration only and restorations associated with different tapered post systems (glass fibre, carbon fibre, titanium and zirconia ceramic) were also evaluated, resulting in six experimental models. A static chewing pressure of 2.16 N mm^{-2} was applied to two areas of the palatal surface of the tooth. Stress distribution was analysed under a general condition and in the structures of the models separately.

Results The maximum stresses were concentrated as follows: at the cemento-enamel junction in the model with a sound maxillary central incisor, restored with CR and with a composite resin restoration associated with fibre posts; in the enamel at the post–enamel interface on the palatal surface of the model with a titanium post; and in the post of the model with zirconia ceramic post.

Conclusions None of the restorations evaluated was able to recover the stress distribution of the sound tooth. The models restored with composite resin associated with a glass or carbon fibre post had similar stress distributions to that of the model restored with CR. The different post materials were shown to have a substantial influence on stress distribution, with less stress concentration when fibre posts were used.

Keywords: biomechanical behaviour, endodontically treated teeth, finite element analysis, post.

Received 29 December 2009; accepted 16 June 2010

Introduction

It has become increasingly difficult for practitioners to select materials and restorative techniques, because of the large number of restorative treatment options. Depending on the remaining coronal tooth structure and technique used (direct or indirect), restorations can involve either a cast post and core or a prefabricated post (Spazzin *et al.* 2009). When prefabricated posts are indicated, glass fibre, carbon fibre, titanium and zirconia ceramic posts (ZC) are available.

The main function of a post is to retain the core material; it does not reinforce the root (Sorensen & Martinoff 1984, Assif *et al.* 1993, Assif & Gorfil 1994, Pierrisnard *et al.* 2002). Moreover, posts may interfere

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with the mechanical resistance of teeth, increasing the risk of damaging the remaining tooth structure (Akkayan & Gulmez 2002).

In posterior teeth, the use of posts is unnecessary in many cases, especially in molars, where the use of the pulpal chamber is often advantageous to provide the stability and retention for the core material. Guidelines for the preparation, as well as the decision to use a post, are dictated by the amount of remaining coronal substance (Lander & Dietschi 2008).

In the case of incisor teeth, the flexural behaviour of posts should be considered (Heydecke *et al.* 2001). Mechanically, the maxillary central incisor behaves like an elastic beam fixed at one end during function, as is a cantilever when not loaded along its longitudinal axis. In this failure scenario, the flexural and torsional characteristics of posts and cores are more relevant (Newburg & Pameijer 1976, Ruemping *et al.* 1979, Tjan & Miller 1984).

Several studies have evaluated the biomechanical behaviour of restored teeth, using post and core associated with crown restorations. However, teeth restored with direct composite resin have not been extensively evaluated (Grandini *et al.* 2005). The current study used finite element analysis (FEA) to evaluate the three-dimensional stress distribution in a sound maxillary central incisor, in a root filled maxillary central incisor with a crown fracture restored with direct composite resin only (CR) or in association with different prefabricated post systems (glass fibre, carbon fibre, titanium and ZCs), using FEA. The hypothesis tested was that posts do not present influence on the stress distribution when associated with direct composite resin restoration in a root filled maxillary central incisor.

Materials and methods

A model of a sound maxillary central incisor and supporting structures was constructed from illustrations in textbooks (Wheeler 1965, Figun & Garino 1994, Leonardo 2005). All FE models contained a periodontal ligament and cortical and medullar bone, because it has been suggested that these should be considered in the FEA of teeth (Rees 2001). In the model, changes were made to create several variations including a root filled tooth with crown fracture. A tapered prefabricated post and composite resin restorations are also modelled. The illustrations were scanned to obtain digital images that are used to determine the proportional relationship between the buccal, palatal and proximal surfaces. 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 and uploaded onto a computer. The FEA was performed with the Ansys software program (Ansys Inc., Houston, TX, USA).

Six experimental models were constructed:

1. sound maxillary central incisor (ST)
2. maxillary central incisor restored with CR
3. maxillary central incisor restored with composite resin associated with a glass fibre post (GF)
4. carbon fibre post (CF)
5. titanium post (Ti)
6. Zirconic ceramic post (ZC)

The configurations and dimensions of the restored models are presented in Fig. 1. The composite resin restoration was placed 5 mm into the root canal in the CR model. The elastic constants used in the calculations were obtained from the literature (Table 1). With the exception of the glass and CFs, the materials were assumed to be isotropic. Glass and CFs were considered orthotropic, made up of long fibres (glass or carbon) embedded in a polymeric matrix, with different mechanical properties along the direction of the fibre (x direction) and along the other two normal directions (y and z direction). The mechanical characteristics of the glass and CFs are shown in Table 2. E_x, E_y, E_z represent the elastic moduli along the three-dimensional directions, whilst v_{xy}, v_{xz}, v_{yz} and G_{xy}, G_{xz}, 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, dentine, pulp, cortical bone, medullary bone, Gutta-percha, posts and composite resin (the solid corpus), with ten nodes and three degrees of freedom per node. The Shell63 element was used for the resin cement, adhesive system and periodontal ligament (the laminate corpus), with four nodes and six degrees of freedom per node. The adhesive system, resin cement and periodontal ligament presented thicknesses of 10, 70 and 250 μm, respectively (Rees & Jacobsen 1997, Ausiello *et al.* 2004).

The following assumptions were made: there was complete bonding between the post and cement; dentine was assumed to be an elastic isotropic material, and the cementum and dentine were considered a single structure. All of the nodes on the external bone surface were constrained in all directions. A linear static structural analysis was performed to calculate

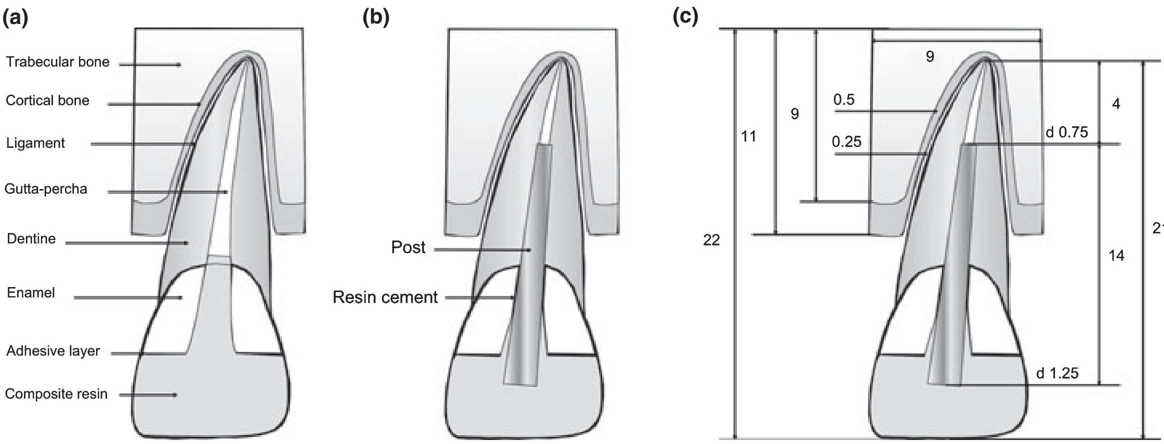

Figure 1 Materials and components in model restored: with composite resin only (a) with composite resin associated with post (b). Dimensions (mm) and post diameters (d) of investigated model restored with composite resin associated with post (c).

Table 1 Material properties in FEA models

Material/component	Elastic modulus (GPa)	Poisson's ratio (v)	Reference
Pulp	0.003	0.45	Toparli *et al.* (2003)
Dentine	15	0.31	Rees & Jacobsen (1995)
Enamel	80	0.30	Rees & Jacobsen (1995)
Periodontal ligament	0.05	0.49	Rees & Jacobsen (1997)
Compact bone	13.8	0.26	Rees *et al.* (2003)
Medullar bone	0.345	0.30	Rees *et al.* (2003)
Resin composite	12.5	0.30	Ausiello *et al.* (2002)
Adhesive system	4.5*	0.30**	*Ausiello *et al.* (2004)
			**Ausiello *et al.* (2002)
Gutta-percha	0.1	0.49	Yaman *et al.* (1995)
Resin cement	7	0.28	Lanza *et al.* (2005)
Titanium alloy	107	0.34	Calister (2002)
Zirconia ceramic	205	0.31	Calister (2002)

FEA, finite element analysis.

Table 2 Orthotropic properties of the fibre posts

Property[a]	Glass fibre post	Carbon fibre post
E_x (GPa)	37	118
E_y (GPa)	9.5	7.2
E_z (GPa)	9.5	7.2
v_{xy}	0.27	0.27
v_{xz}	0.34	0.34
v_{yz}	0.27	0.27
G_{xy}	3.1	2.8
G_{xz}	3.5	2.7
G_{yz}	3.1	2.8

[a]Lanza *et al.* 2005.

the stress distribution under a general condition, remaining tooth structures and restorative materials, under a chewing static pressure of 2.16 N mm^{-2}, applied on the palatal surface in two areas of the enamel for sound MCI and of the composite resin for the other models. 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 cemento-enamel junction and cement–post interface.

The results of an FEA are expressed as stresses distributed in the structures under investigation. These stresses may be tensile, compressive, shear or a combination known as equivalent Von Mises stresses. Von Mises stresses depend on the entire stress field and are a widely used indicator of the possibility of damage occurring (Asmussen *et al.* 2005). The choice of the Von Mises stress criterion was based on the evaluation of the failure predictive potential of the analysis performed, identifying areas of highest stress concentration where possible fatigue failure is more likely to occur (Zarone *et al.* 2006).

Results

When the 3-D models were subjected to simulated masticatory loading, the distribution of Von Mises stress was observed under a general condition, remaining tooth structures (enamel, dentine) and restorative materials (composite resin, cement layer and post), except for ST and CR models, in which some of these structures were not modelled. Maximum stress values found in the models are presented in the Table 3.

General condition

Figure 2 represents stress distribution under a condition of generality. Stresses were concentrated at the cemento-enamel junction on the buccal surface. Maximum stress values found in this region are presented in the Table 3.

Remaining tooth structures

The maximum stresses in enamel were concentrated at the cemento-enamel junction of the buccal face for Models ST, CR, GF and CF (see Fig. 2). The maximum stresses were located at the enamel–post interface on the palatal face for Models Ti and ZC.

Figure 3 represents stress distribution in dentine. Stresses were concentrated between the cervical part of the dentine in the crown, including the cemento-enamel junction, and the corresponding area of the alveolar crest on the buccal face.

Restoring materials

The maximum stresses in the composite resin restoration were concentrated in the pulp chamber and root canal, adjacent to the Gutta-percha, for Model CR. For models with posts, the maximum stresses were located in the layer that covered the palatal surface of the post. Models GF and CF had stress concentrations on the surface corresponding to the composite resin–adhesive interface in the direction of the palatal surface. Moreover, Model GF also had stress concentrations in the direction of the buccal surface (Fig. 4).

Maximum stresses in the cement layer were located in the area corresponding to cervical part of the root between the cement-enamel junction and bone crest. Models GF and CF had areas of maximum stress and stresses distributed throughout the entire layer. Models Ti and ZC had maximum stress levels concentrated in the middle third of the post, with low stress levels in the apical and coronal parts of the cement layer (Fig. 5).

The maximum stresses in the post were concentrated between the middle and apical thirds for Models Ti and ZC. The maximum stresses were located in the middle third of the post for Models GF and CF (Fig. 5).

Discussion

Two statistical methods can be used in FEA according to Dar *et al.* (2002). The Taguchi method explores the sensitivity of a model to input parameters and reduces the experimental effort required to investigate multiple factors. The probabilistic approach restores a degree of uncertainty that is normally lost when modelling a real system. However, this could be computationally very costly, as a large number of models may have to be run, especially if there is a large number of input variables each having an associated uncertainty. Owing to the great variability in the element structures of the model analysed and its clinical loading, a statistical method

Table 3 Maximum stress values (MPa) found in the models

		Structures				
Model	General condition	Enamel	Dentine	Composite resin	Cement layer	Post
ST	45.86	45.86	23.53	–	–	–
CR	24.39	25.96	18.90	6.06	–	–
GF	24.94	26.52	17.39	3.61	1.82	2.95
CF	24.97	26.55	17.42	4.46	1.84	3.23
Ti	24.03	31.34	16.52	5.47	2.45	21.73
ZC	30.82	39.12	16.00	7.12	2.63	39.65

CF, carbon fibre post; CR, composite resin only; GF, glass fibre post; ZC, zirconia ceramic post.

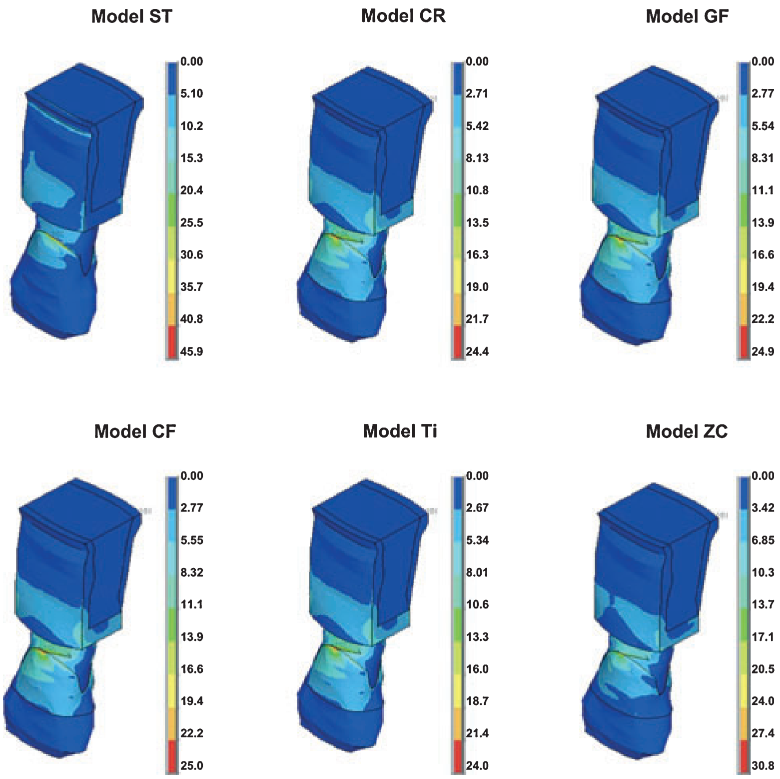

Figure 2 Qualitative analysis of the stress distribution (in MPa) under a general condition in the different experimental models using Von Mises stress figures and core gradients.

would be extremely arduous and complex, or even impracticable.

The FEA demonstrated changes in the stresses induced in some of the models evaluated; consequently, the hypotheses tested were partially rejected. None of the reconstructions evaluated was able to restore the stress distribution of the sound maxillary central incisor. Placement of composite resin or an endodontic post created an unnatural restored structure, as the root canal space was filled with a material that is unlike pulp with regard to stiffness. This finding is in agreement with Zarone *et al.* (2006) who used the FEA in a maxillary central incisor restored with a core associated with a crown.

In Model ST, the stresses were almost uniformly distributed within its structures. Nevertheless, the stresses were concentrated in the cervical region, in which the cemento-enamel junction creates a physiological discontinuity of the mechanical properties of the tissues. The high stress levels recorded in the cervical part of the buccal surface resulted from the flexure that occurred in the models. When the enamel coats the coronal dentin, it creates stiffness, transferring stresses to the external interface at the limit with root dentine. Some authors observed a tendency towards rotation of the coronal portion, with the fulcrum on the buccal face and tensile stress on the palatine face (Yettram *et al.* 1976, Ho *et al.* 1994). All the other models had stress concentration at the cemento-enamel junction on the buccal face. For Models CR, GF, CF and Ti, the stresses in this area were distributed over a large surface, extending to almost all the remaining enamel, with little differences in the stress levels on the external surface. This observation is agreement with Lanza *et al.* (2005) and some studies using external strain gauge measurements; however, all these authors used crowns as restoration (Leary *et al.* 1989, Yaman *et al.* 1998, Heydecke *et al.* 2001). For Models ZC, the stresses were concentrated in a small area at the cemento-enamel junction because of lower flexure of the model caused by the stiffness of the post. The models had similar behaviour on the palatal surface, although lower stress values were found.

The maxillary central incisor restored with composite resin associated with fibre posts did not reveal changes in the stress distribution compared with the maxillary central incisor restored with CR, whilst the use of the titanium or ZC created changes in the

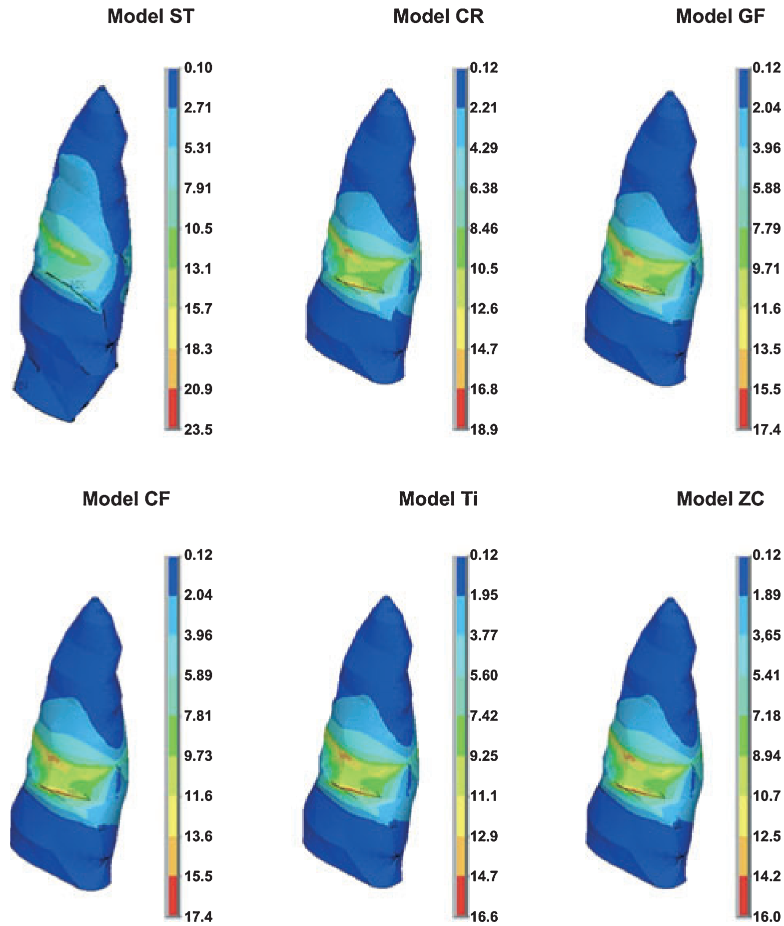

Figure 3 Qualitative analysis of the stress distribution (in MPa) for dentine in the different experimental models using Von Mises stress figures and core gradients.

stress levels in some areas, particularly at the interfaces. The literature has suggested that the interfaces of materials with different elastic modulus represent the weakest point of a restorative system (Assif & Gorfil 1994, Ausiello *et al.* 1997). The parts of the investigated models were separated for more accurate structural analysis; except for the adhesive layer, which is thin, and consequently, there were few changes in maximum stress values. The separate analysis showed that the use of titanium and ZCs created less stress on the external dentine surface because of the lower flexibility caused by presence of a core material with high stiffness; consequently, these posts received more stresses in their structure, and in the cement layer, increasing the risk of fracture and debonding. Pegoretti *et al.* (2002) in a 2-D FE study concluded that GFs resulted in lower stress 'inside the root' than the stress created by other post systems with higher elastic modulus. However, these authors failed to mention that these stresses were not found in dentine, but within the post itself (Zarone *et al.* 2006).

Ceramic posts are stronger than prefabricated metal and fibre posts, but they have a lower resistance to crack propagation (Asmussen *et al.* 1999). This fact, associated with the high stress concentration in the post in Model ZC, might explain the finding of post fractures without root fractures (Fokkinga *et al.* 2004). This is probably explained by the energy being absorbed by the post, reducing the stress created in dentine. Additionally, the fact that post fracture can occur near the elastic limit, characterizing a friable material (Pfeiffer *et al.* 2006). Some authors have stated that ceramic post fracture can result in tooth loss, because it is almost impossible to remove the retained fragment (Butz *et al.* 2001, Heydecke *et al.* 2002). Fibre post system failures are normally also because of post fractures (Fokkinga *et al.* 2004), but they are easier to remove without the risk of perforating the root, because a bur can be used to remove the

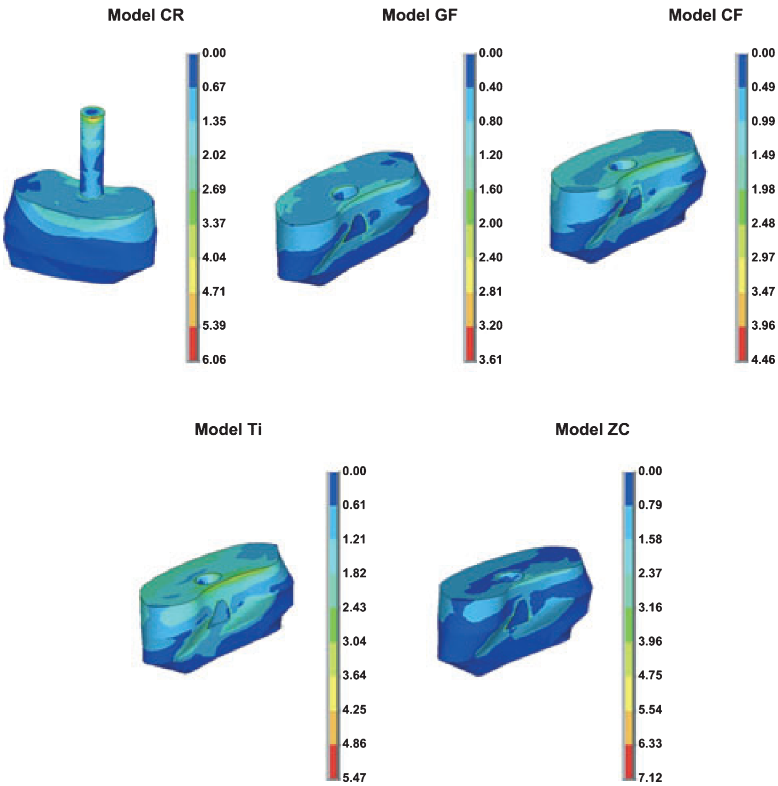

Figure 4 Qualitative analysis of the stress distribution (in MPa) for composite resin restorations in the different experimental models using Von Mises stress figures and core gradients.

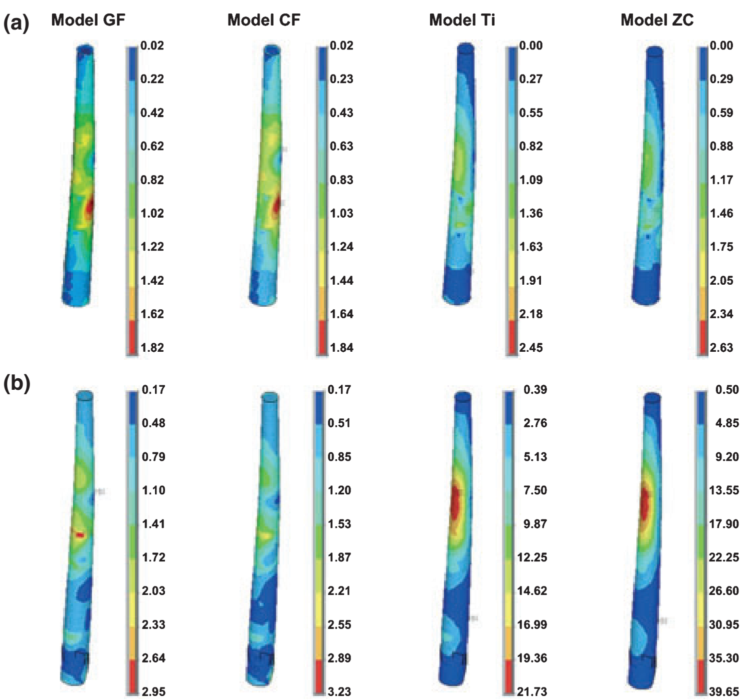

Figure 5 Qualitative analysis of the stress distribution (in MPa) for resin cement layer (a) and for post (b) in the different experimental models using Von Mises stress figures and core gradients.

remaining portion (Mannocci *et al.* 1999). Some laboratory studies state that metal posts failures are associated with a higher number of catastrophic failures. Whereas fibre posts are less destructive in fractures occurring above of the bone level (Isidor *et al.* 1996, Sidoli *et al.* 1997). Other factors should be considered as regards fibre posts, such as high fatigue and tensile strength and Young's modulus comparable with that of dentine. These posts are also compatible with Bis-GMA resin used in bonding procedures, and they can, therefore, be bonded in root canals with adhesive resin cement and bonding systems. Bonding agents transmit stress between the post and the root structure, reducing stress concentration and preventing fracture.

An interesting consideration is that this study evaluates the behaviour of the composite resin. In Model CR, the composite resin had the highest stresses concentrated in the region corresponding to the filling of the pulp chamber and root canal, near the Gutta-percha. In the models with posts, high stress levels occurred in the layer that covered the post on the palatal face, with highest values for Models Ti and ZC. In Models GF and CF, the stresses in this region were lower, but the surface corresponding to the resin–adhesive interface had high stress levels in the palatal direction. Moreover, Model GF had high stress levels in the buccal direction. This higher potential for flexure occurred in Models CR, GF and CF could result in loss of marginal seal, leading to fluid and bacterial microleakage. Studies using cyclic mechanical fatigue followed by scanning electron microscopy analysis or microleakage tests are required to corroborate this statement.

The association of post with restoration has been evaluated, showing that fracture resistance is not affected by the presence or absence of a fibre posts (Sahafi *et al.* 2005, Salameh *et al.* 2006). As an exception, Sorrentino *et al.* (2007) concluded that the fracture resistance of root filled premolars with mesial–occlusal–distal cavity preparations is associated with a post, and the use of fibre posts resulted in restorable fractures, whereas the use of resin composite alone caused catastrophic root fractures. However, the teeth of the control group (restored with flowable and microhybrid resin composites) were not significantly different in terms of fracture resistance to teeth restored with posts, and the failure mode was similar (Sorrentino *et al.* 2007). Further studies are necessary to clarify these contradictions. Moreover, a decrease in the number of interfaces and improvement in the bonding agents should be also considered. Based on the data of this study and findings in the dental literature, the use of the posts could be dispensed within restorations of this type, although the quantity of remaining structure could have an influence on the stress distribution. Further laboratory and clinical studies must be conducted to verify these hypotheses.

Conclusion

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

1. None of the restorations evaluated was able to recover the stress distribution of the sound maxillary central incisor.

2. The maxillary central incisor restored with CR had stress distributions similar to that of the model restored with a glass or CF.

3. The different post systems changed the distribution of stress induced in the tooth–restoration complex. The models restored with titanium and zirconia ceramic posts had high stress levels in the post body and resin composite that covered the post, whilst the models with fibre posts had lower stress concentrations.

4. These findings suggest that posts could be dispensed when using direct composite resin to restore a horizontal crown fracture in the middle of the crown. Fibre posts should be preferred when the clinician has opted to use a post in association with the restoration.

Acknowledgements

The authors thank the Faculty of Mechanical Engineering of the Engineering and Architecture School, University of Passo Fundo, RS, Brazil, for its generous help with the element finite analysis.

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