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Monoblocks in root canals: a finite elemental stress analysis study

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Abstract

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Aim To investigate using finite element stress analysis (FEA) primary, secondary and tertiary monoblocks created either by adhesive resin sealers or by different adhesive posts and to evaluate the effect of interfaces on stress distribution in incisor models.

Methodology Seven maxillary incisor FEA models representing different monoblocks using several materials were created as follows: (a) primary monoblock with Mineral Trioxide Aggregate; (b) secondary monoblock with sealer (MetaSEAL) and Resilon; (c) tertiary monoblock with EndoREZ; (d) primary monoblock with polyethylene fibre post-core (Ribbond); (e) secondary monoblock with glass-fibre post and resin cement; (f) tertiary monoblock with bondable glass-fibre post; (g) tertiary monoblock with silane-coated ceramic post. A 300 N load was applied from the palatal surface of the crown with a 135° angle to the tooth long axis. Materials used in the study were assumed to be homogenous and isotropic except the glass-fibre post; the results are expressed in terms of von Mises criteria.

Results Maximum stresses were concentrated on force application areas (18–22.1 MPa). The stresses within the models increased with the number of interfaces both for the monoblocks created by the sealers (1.67–8.33 MPa) and for the monoblocks created by post-core systems (1.67–11.7 MPa).

Conclusions Stresses within roots increased with an increase in the number of the adhesive interfaces. Creation of a primary monoblock within the root canal either by an endodontic sealer or with an adhesive post-core system can reduce the stresses that occur inside the tooth structure.

Keywords: endoREZ, finite element analysis, glass-fibre post, monoblock, MTA, polyethylene fibre post, post and core, Resilon, stress, tooth biomechanics.

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Introduction

With the application of adhesive technology to endodontics, the term *monoblock* has become familiar (Tay & Pashley 2007). Monoblock units can be created in a root canal system either by adhesive root canal sealers such as EndoREZ (Ultradent, South Jordan, UT, USA; Eldeniz *et al.* 2005); RealSeal (SybronEndo, Orange, CA, USA; Salz *et al.* 2005)/Epiphany (Pentron Clinical Technologies, Wallingford, CT, USA; Shipper *et al.* 2004) or MetaSEAL (Parkell, Farmington, NY, USA; Belli *et al.* 2008) in combination with a bondable root filling material Resilon (Resilon Research LLC, Madison, CT, USA; Teixeira *et al.* 2004). Monoblocks can also be created using adhesive post systems, which have similar elastic moduli to dentine such as carbon fibre-reinforced posts (Dallari & Rovatti 1996); prefabricated glass-fibre posts (Akkayan & Gülmez 2002); customized polyethylene fibre posts (Eskitascioglu *et al.* 2002) or customized glass-fibre posts (Lassila *et al.* 2004).

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In a previous review (Tay & Pashley 2007), the monoblocks created in the root canal spaces were classified as primary, secondary or tertiary depending on the number of the interfaces present between the bonding substrate and the bulk core material (Fig. 1). According to this classification, a primary monoblock has only one interface that extends circumferentially between the material and the root canal wall. Mineral Trioxide Aggregate (MTA; ProRoot MTA, Dentsply, Tulsa, OK, USA) represents a contemporary version of the primary monoblock (Fig. 1a). Secondary monoblocks have two circumferential interfaces. Resilon is applied using a methacrylate-based sealer to root dentine and can be classified as a type of secondary monoblock (Fig. 1b). Tertiary monoblocks are those in which a third interface is created between the bonding substrate and abutment material as in the EndoREZ system (Fig. 1c). In this system, conventional gutta-percha cones are coated with a proprietary resin coating (Tay *et al.* 2005a).

When this classification is adapted to the post-core systems, a customized polyethylene fibre post-core system such as Ribbond (Ribbond Inc., Seattle, WA, USA) can create a primary monoblock in a root. Before creating a post-core build-up restoration with this system, impregnation of polyethylene fibre with a dual curable adhesive system is a necessary step (Belli & Eskitascioglu 2008). Impregnated fibre is then condensed into the root canal in combination with a dual curable resin cement. A combination of polyethylene fibre, adhesive resin and dual curable cement creates a structure with an elastic modulus of 23.6 GPa (Eskitascioglu *et al.* 2002). Only one interface occurs between the polyethylene fibre post-core system and the root canal (Fig. 1d); therefore, polyethylene fibre post-core build-ups can be considered as a primary monoblock system.

Prefabricated post systems bonded to root canal dentine via resin cements represent a secondary monoblock (Fig. 2e), and fibre posts that contain an extra silicon coating such as DT Light (VDW GmbH, Munich, German) or ceramic posts that require a silane coating such as Cosmopost (Ivoclar, Vivadent, AG, Schaan, Liechtenstein) can be considered as tertiary monoblocks.

Root filled teeth are reported to be more prone to biomechanical failure when compared to teeth with vital pulps (Tamse *et al.* 1999) mostly because of loss of tooth structure owing to carious lesions and/or cavity preparation (Sedgley & Messer 1992). Most clinical failures can be ascribed to physiologic masticatory or parafunctional forces when repeated over long periods of time, also known as fatigue stress (Dietschi *et al.* 2007). Stress is produced within a structure as a result of internal resistance generated to counter the applied force. The nature of the distribution of stress within the

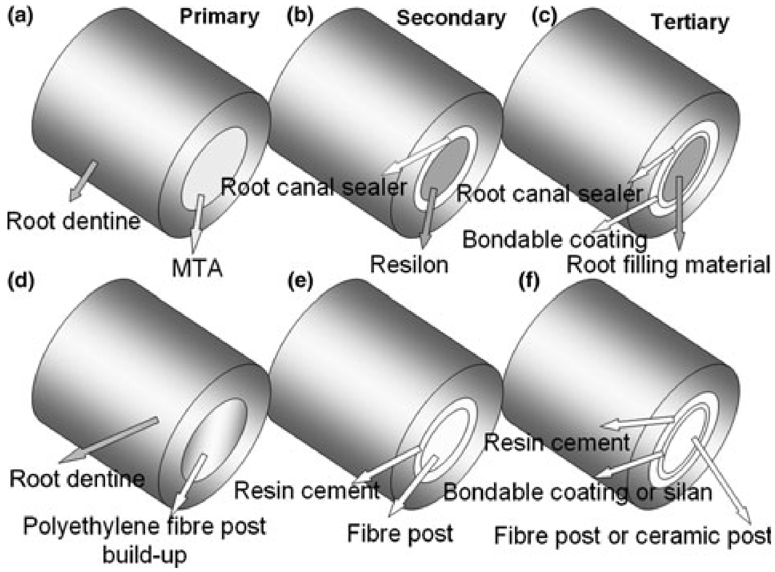

Figure 1 Schematic representation of the monoblocks created in the root canal spaces classified as primary, secondary or tertiary depending on the number of the interfaces present between the bonding substrate and the bulk material core.

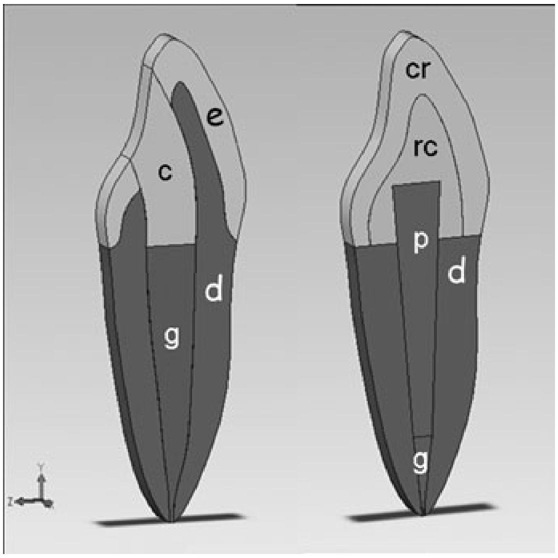

Figure 2 Three-dimensional maxillary central incisor models created for finite element stress analysis; e, enamel; d, dentine; c, composite resin; g, gutta-percha; cr, ceramic restoration; rc, resin-core; p, post.

structure load changes because of the direction of the load applied and the shape of the structure (Kishen & Asundi 2002). Concentrations of stress from a biomechanical perspective indicate regions of potential failure. Therefore, biomechanical studies are necessary to highlight the behaviour of a treated tooth to functional forces.

The aim of this finite element stress analysis (FEA) study was to investigate primary, secondary and tertiary monoblock models created either by endodontic materials or by post-core structures using FEA models and to evaluate the effect of different monoblock models on stress distribution in remaining tooth structures. The hypothesis tested was that increased interfaces created in FEA monoblock models either by an endodontic or by post-core material do not have an effect on stress distribution.

Materials and methods

The study was conducted using a 3-dimensional FEA method and a FE structural analysis programme (ANSYS ver.10.0; ANSYS, Houston, TX, USA). Three-dimensional maxillary central incisor (Wheeler 2003) FEA models were created including the following structures: e, enamel; d, dentine; c, composite resin; g, gutta-percha; cr, ceramic restoration (IPS e-max Press; Ivoclar Vivadent AG, Schaan, Liechtenstein); rc, resin-core (Biscore; Bisco, Vancouver, Canada); p, post (Fig. 2). The models were modified to demonstrate (i) primary monoblock with MTA; (ii) secondary monoblock with MetaSEAL and Resilon; (iii) tertiary monoblock with EndoREZ; (iv) primary monoblock with polyethylene fibre post-core system; (v) secondary monoblock with glass-fibre post and resin cement; (vi) tertiary monoblock with bondable glass-fibre post; (vii) tertiary monoblock with silane-coated ceramic post as illustrated in Fig. 1 (Tay & Pashley 2007).

The mathematical models included 20 471 nodes and 13 872 tetrahedral solid elements. Materials used in the study were assumed as homogenous and isotropic except the glass-fibre post. The glass-fibre post was considered to be made of long fibres (glass-fibre) embedded into a polymeric matrix. This composite material is considered orthotropic, so that it shows different mechanical properties along the fibre direction (x direction) and along the other two normal directions (y and z direction; Lanza *et al.* 2005). The elastic properties of the isotropic materials (Young's modulus [E] and Poisson's ratio [μ]) were determined from the manufacturers and the literature and are provided in Table 1. The mechanical characteristics of the fibre posts are reported in Table 2 (Asmussen *et al.* 1999, Lanza *et al.* 2005). An occlusal force of 300 N was applied from the palatal surface of the crown at a 135° angle to the tooth long axis (Fig. 3). Nodes at the outer surface of roots were assumed as fixed in all directions to calculate the stress distribution. Results are presented by considering von Mises criteria. Calculated numeric data were transformed into colour graphics to

Table 1 The elastic properties (Young's modulus [E] and Poisson's ratio [μ]) of isotrophic materials

Material	Elastic modulus (E) (GPa)	Poisson's ratio (μ)
IPS e-max core[a]	95	0.24
IPS e-max veneer[a]	65	0.24
Polyethylene fibre[b]	23.6	0.32
Composite core[a]	12	0.30
Dentin[b]	18.6	0.31
Resin cement[a]	8	0.3
Gutta-percha[c]	0.074–0.079	0.45
Resilon[c]	0.087–0.128	0.45
Adhesive[a]	10.5	0.28
Mineral trioxide aggregate[c]	15–30	0.314

[a] Acquired from manufacturer.
[b] Eskitascioglu *et al.* (2002).
[c] Tay & Pashley (2007).

Table 2 The elastic properties of the orthotrophic materials

Property	Glass post
E_x (GPa)	37
E_y (GPa)	9.5
E_z (GPa)	9.5
NU_{xy}	0.27
NU_{xz}	0.34
NU_{yz}	0.27
G_{xy}	3.10
G_{xz}	3.50
G_{yz}	3.10

E_x, E_y and E_z represent the elastic moduli along the three directions, whilst NU_{xy}, NU_{xz}, NU_{yz} and G_{xy}, G_{xz}, G_{yz} are, respectively, the Poisson's ratios and the shear moduli in the orthogonal planes (*xy*, *xz* and *yz*; Asmussen *et al.* 1999, Lanza *et al.* 2005).

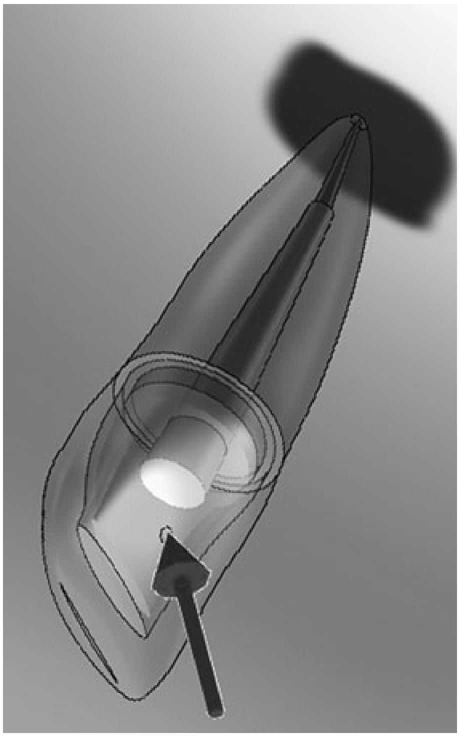

Figure 3 Three-dimensional maxillary central incisor model created for finite element stress analysis and the direction of the load.

better visualize mechanical phenomena in the models. The FEA results are presented as stresses distributed in the investigated structures.

Results

Total and maximum von Mises stress values recorded within the root dentine and core material are summarized in Table 3. The maximum von Mises stresses were primarily located at the force application areas (18–22.1 MPa; Figs 4 and 5). Stress amounts observed at root dentine and core material at the FEA models in the case of primary, secondary or tertiary monoblocks created by either endodontic materials or post-core structures are reported in Fig. 6. In all cases, the stress increased from the coronal 1/3 of the root to its maximum value located at 'D' point (cervical region) and than it decreased. Maximum equivalent stresses occurred at the level of the cervical region both on the buccal and on the palatal aspect of the roots in MetaSEAL (21.5 MPa) and EndoREZ (23 MPa) models (Fig. 4).

The palatal side of the MTA model showed a decreased stress accumulation (8.33–13.3 MPa) when compared to the others. It is obvious that the composite resin in the access cavity has changed the stress direction when compared to the natural tooth structure and increased stress at the coronal region. The stress is kept inside the crown of the tooth in the natural tooth model but directed under load towards the root in root filled tooth models (Fig. 4).

The MTA-treated model revealed that the material kept the stress inside of the material body (1.67–3.33 MPa) and directed towards the root via the root canal; therefore, stress at the palatal cervical region decreased under loading (Fig. 4). On the other hand, the secondary monoblock model revealed stress accumulation at the interface between the Resilon and MetaSEAL (13.3–20 MPa). Stress distribution through the gutta-percha (5–6.67 MPa) increased in the tertiary monoblock model created by EndoREZ. In contrast to the other endodontic models (1.67–3.33 MPa), the stress values at the interface were high in this model (6.67–10 MPa).

When the monoblock models created with post systems were evaluated under loading (Fig. 5), maximum equivalent stresses occurred at the level of the cervical region both on the buccal and on the palatal aspect of the roots (8.33–20 MPa). The primary monoblock model created with polyethylene fibre revealed stress distribution at the coronal region ranging from 1.57 to 5 MPa but not in the root structure when compared to the tertiary monoblock models, which were created either by bondable glass-fibre posts (6.67–10 MPa) or by silane-coated ceramic posts (6.67–13.3 MPa). Primary (polyethylene fibre post) and secondary monoblock (glass-fibre post) models showed similar stress values and distribution at the coronal region decreasing towards the root (from 6.67 to 1.67 MPa). Stress values along the cement glass-fibre or ceramic interface ranged from 1.67 to 15 MPa

Table 3 Summary of total and maximum von Mises stress values recorded within the root dentine and core material

		Primary		Secondary		Tertiary		
	Natural tooth	MTA	Ribbond	MetaSEAL Resilon	Glass fibre	EndoREZ	Glass fibre	Ceramic
Root dentine								
Max	12.6	14.7	12.0	21.5	14.0	23.0	13.6	13.3
Sum	258.94	233.82	259.49	433.44	440.09	459.02	483.92	562.22
Core								
Max	19.1[a]	6.9[a]	18.9	7.0[a]	19.0	7.1[a]	19.7	19.7
Sum	485.88[a]	323.87[a]	469.90	1669.70[a]	904.68	2555.1[a]	956.01	955.08

[a]Core structure is coronal dentine.

Max, maximum; Sum, total stress values; MTA, mineral trioxide aggregate.

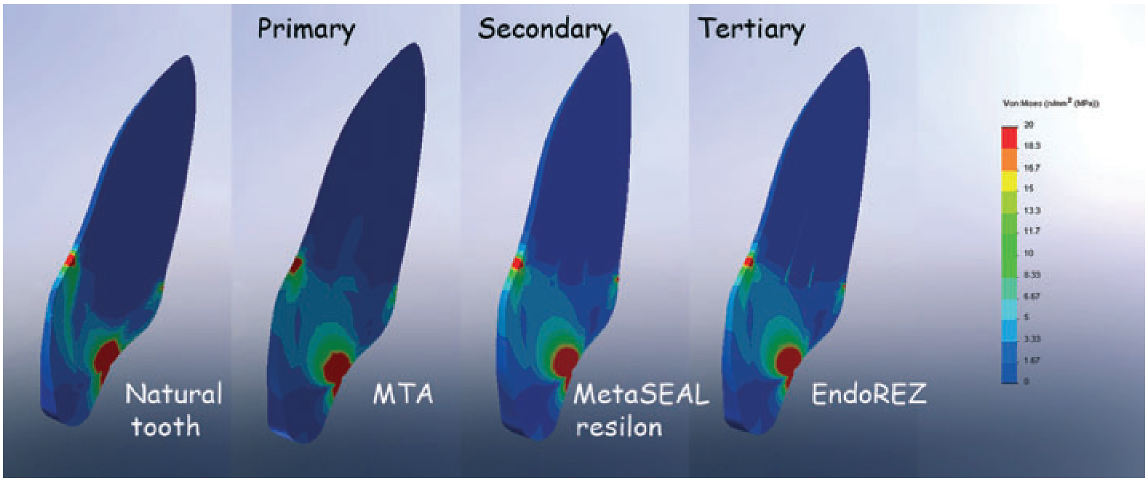

Figure 4 Von Mises stress distribution calculated in corresponding finite element models including endodontic obturation materials (MPa).

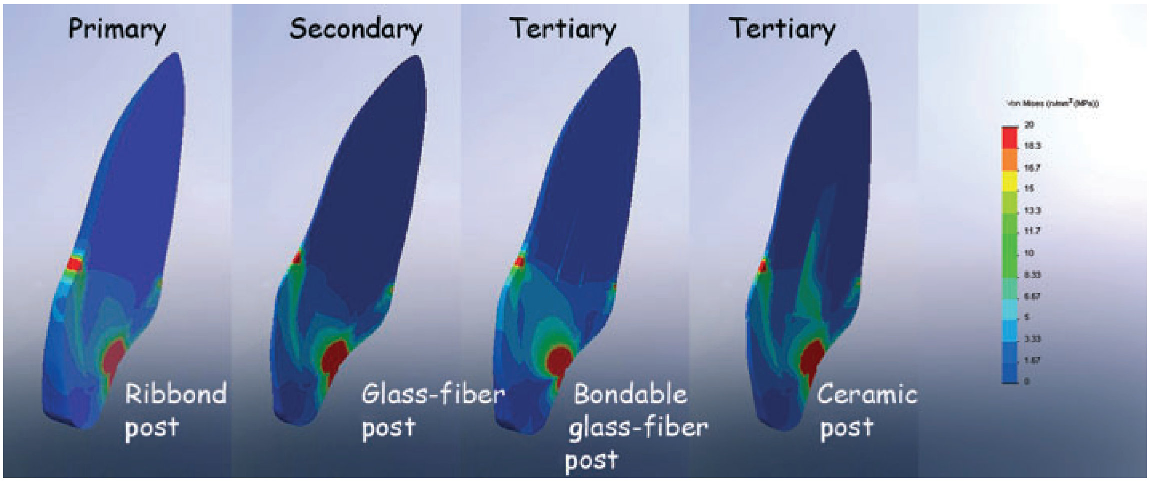

Figure 5 Von Mises stress distribution calculated in corresponding finite element models including post-core restorative materials (MPa).

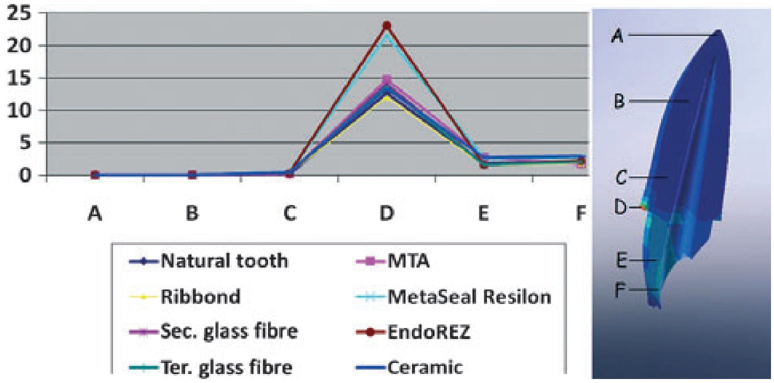

Figure 6 Stress observed in root dentine and core material in the finite element stress analysis models in the case of primary, secondary or tertiary monoblocks created by either endodontic materials or by post-core structures. The reference points in the figure are measured as shown in the right side of the same figure. In all cases, the stress increased from the coronal 1/3 of the root to its maximum value located at point 'D' (cervical region) and then it decreased.

for tertiary monoblock models (bondable glass-fibre; 1.67–5 MPa and the silane-coated ceramic post; 1.67–15 MPa). Furthermore, the stress was directed through the root in tertiary monoblock models. In contrast to the glass-fibre post, the ceramic post retained the stress inside the body of the post.

Discussion

This study was built on the assumption that a monoblock can be achieved in root canal treatment and the placement of post-core. The concept of creating mechanically homogenous units within root dentine is excellent in theory; however, accomplishing these ideal monoblocks in the canal space is challenging (Tay & Pashley 2007) because bonding to dentine is compromised by volumetric changes that occur in resin-based materials during polymerization such as methacrylate-based sealers (Bergmans *et al.* 2005) or adhesive cements (Bouillaguet *et al.* 2003), high cavity configuration factors (C-factor) inside long arrow canals (Tay *et al.* 2005b), debris on canal walls (Burleson *et al.* 2007) and differences in regional bond strengths (Bouillaguet *et al.* 2003). Accuracy of the experimental model is crucial for the validity of the results of a FEA study. FEA consists of a computer model of a material or design that is stressed and analysed for specific results. The first issue to understand in FEA is that it is fundamentally an approximation (Apicella 2008). Many details are idealized, simplified or ignored (Eskitascioglu *et al.* 2002, Apicella 2008). The loading of the model is an approximation of what happens in the real world; the boundary conditions approximate how the structure is supported by the outside world and the material properties are assumed as approximate (Apicella 2008). On the other hand, FEA analysis, models and simulations have been used for many years to estimate the biomechanical behaviour of materials and structures where these predicted variables are impossible to measure directly (Eskitascioglu *et al.* 2002, Apicella 2008). Furthermore, previous studies indicated that FEM results confirm the results of laboratory studies (Eskitascioglu *et al.* 2002, Asmussen *et al.* 2005).

Several techniques and methods can be used to evaluate distribution of functional stresses in a structure including photoelastic studies, 2-dimensional FEA or 3-dimensional FEA (Dietschi *et al.* 2007). Three-dimensional FEA is generally preferred to obtain a realistic analysis because 2-dimensional modelling may not represent tooth irregularities and may neglect several important details (Toparli *et al.* 1999). In the present study, a 3-dimensional FEA method was used to evaluate the pattern of stress distribution in the roots filled either with endodontic materials or restored with different post-core systems. The FEA model used was based on a maxillary incisor. Three-dimensional models were constructed for this purpose, and the structures in the models were all assumed to be homogeneous isotropic and possess linear elasticity except the glass-fibre post. The majority of the fibre-reinforced composite (FRC) posts contain a resin matrix with embedded glass or quartz fibres. The fibres are designed to provide high tensile strength, and the resin matrix is supposed to withstand compressive stresses and absorb stresses in the entire post system (Seefeld *et al.* 2007). The mechanical behaviours of fibre-reinforced posts depend on many factors such as direction or orientation of the fibres (Grandini *et al.* 2005) individual properties of fibres and matrix (Drummond & Bapna 2003), the density, diameter and adhesion of the fibres to the resin matrix (Grandini *et al.*2005), etc. They have completely different behaviour when loaded in compression and in flexure (Novais *et al.* 2009). Therefore, in this study, the glass-fibre post was considered to be made up of long fibres (glass-fibre) embedded into a polymeric matrix; this composite material is considered orthotropic (Lanza *et al.* 2005).

The FEM results are presented as stresses distributed in the investigated structures. These stresses may occur as tensile, compressive, shear or a stress combination. The global (x, y and z directional axes) combination of the absolute values squared of all stresses is known as von Mises stresses (Ricks-Williamson *et al.* 1995). Von Mises stresses depend on the entire stress field and are widely used as an indicator of the possibility of damage occurrence (Pegoretti *et al.* 2002). The von Mises criterion was used in this study to indicate the bounds for principal stress as is often done in composite materials and has already been shown previously to successfully indicate stress distribution in composite resin cores with fibre posts (Okamoto *et al.* 2008).

The development of the stress concentrated at the loading area was in agreement with previous FEM studies (Imanishi *et al.* 2003, Eraslan *et al.* 2009). Contrary to the normal tooth, more stress concentrated in the remaining tooth structure especially in the tertiary monoblock created models (Figs 4 and 5). The stress inside the root structure increased with the increased interfaces. This result confirms the concept that the interfaces of materials with different moduli of elasticity represent the weak point of a restorative system, as the toughness/stiffness mismatch influences the stress distribution (Zarone *et al.* 2006).

The major changes in tooth biomechanics are attributed to the loss of tissue in root filled teeth (Dietschi *et al.* 2007). In a biomechanical aspect, restoration of root filled teeth with materials having a similar elastic modulus to dentine can save the remaining tooth structure. In other words, rigid materials can lead to failure of the restorations or can result in fracture of the remaining tooth structure. Metals and ceramics used for post fabrication present moduli of elasticity that are above that of dentine (Dietschi *et al.* 2007). Although stiff post restorations increase fracture resistance of the roots, when failure occurs, the failure mode is mostly non-restorable (Eskitascioglu *et al.* 2002, Maccari *et al.* 2003). Confirming these mechanical tests, the results of this study indicated that ceramic posts had higher stress values within the root structure when compared to the polyethylene-fibre or glass-fibre post restored root model. The forces were transmitted directly to the post/tooth interface without stress absorption (Asmussen *et al.* 1999), and this feature is considered to account for the catastrophic fractures (Akkayan & Gülmez 2002).

The stress concentrated in the cervical region of the tooth was also in congruence with a digital photoelasticity study conducted by Kishen & Asundi (2002). The polyethylene fibre post-core system is considered to create primary monoblocks in the present study. The polyethylene fibre used was not pre-impregnated and is normally used in combination with an adhesive resin and resin luting cement. Therefore, the elastic modulus of this combination (Eskitascioglu *et al.* 2002) was used when creating the FEA models. Von Mises stress values indicated that the stress occurring coronally was high in primary monoblock model; on the other hand, no stress was directed towards the root. Coronal failure can be expected instead of root failure or 'restorable' failure instead of 'non-restorable' failure in these roots after loading as previously reported by Eskitascioglu *et al.* (2002).

The stiffness of Resilon and gutta-percha is too low to reinforce the roots (Williams *et al.* 2006), and adhesive procedures alone are not sufficient to strengthen dentine if the material is not stiff enough (Grande *et al.* 2007). In the present study, Resilon and gutta-percha were used to create secondary and tertiary monoblock models and MTA was used to create a primary monoblock in the root canal system, although this kind of restoration is not clinically relevant. The MTA-treated model showed that the material maintained the stress inside the body of the materials and was directed towards the root via the root canal; therefore, stress at the lingual cervical region decreased under loading (Fig. 4, 8.33–11.7 MPA). It can be speculated that if the root canal system is restored only by MTA, cervical crown fractures can be prevented; on the other hand, root dentine may be weakened confirming the results of a previous study by White *et al.* (2002).

The teeth root filled with Resilon/Epiphany are reported to have a greater resistance to vertical root fracture when compared to similar teeth filled with gutta-percha (Teixeira *et al.* 2004). In the present FEA study, a recently introduced resin-based root canal sealer, MetaSEAL, was used in combination with Resilon to create a secondary monoblock. According to the manufacturer's instructions, this sealer can be used either with Resilon or with gutta-percha. Both Resilon and gutta-percha restored models had stress distribution towards the root (Fig. 4; Belli *et al.* 2008). Although the bondable gutta-percha restored model showed more stress areas towards the root, this probably occurred because of increased interfaces rather than because of the properties of the materials.

Many detrimental effects during restoration procedures are reported to be produced because of lack of understanding of biomechanical principles underlying treatment (Caputo & Standlee 1987). Biomechanical studies are crucial to highlight the behaviour of a post endodontically restored tooth to functional forces (Kishen & Asundi 2002). This study aimed to determine stresses that occur during restoration of root filled teeth either with a root canal sealer or with a post-core restoration because accumulation of stress, from a biomechanical perspective, indicates regions of potential failure owing to the formation of cracks or fatigue. The access cavity was restored with composite resin in root canal sealer models, and the crowns of the teeth were restored with full ceramic restorations in the post models to simulate clinical conditions. As a result, the null hypothesis is rejected. Monoblocks created in FEA models either by an endodontic or by post-core material effected stress distribution, and the stresses within the FEA models increased with the number of adhesive interfaces. The clinical importance of this study is that when a clinician realizes that the strength of the remaining tooth structure is too weak to resist overloads, than perhaps using materials which create a primary monoblock would be better to limit the amount of stress concentrated on these weak parts of the tooth. This would decrease the possibility of root fracture. On the other hand, the effect of shrinkage and contraction stress of the resin-based materials in combination with the unfavourable configuration factor within the root canal (Bergmans *et al.* 2005, Tay *et al.* 2005b) should not be disregarded. Debonding of posts because of contraction stress of the cement was found as the most common mode of failure for posts (Cagidiaco *et al.* 2008). Like resin composite restoratives, resin cements contract during setting, which causes stresses in the thin adhesively bonded cement layer (De Gee *et al.* 1993). Shrinkage stresses that occur with polymerization of methacrylate-based resins are higher in low-filled, lower viscosity resin cements and root canal sealers than highly filled resin composites (Condon & Ferracane 2000, Sakaguchi *et al.* 2004). The lack of relief of shrinkage stresses created in deep, narrow canals is another major problem (Ferracane 2005). In cement layers with uniform layer thickness, it is possible to predict with FEA the contraction stresses with the parameters found (De Jager *et al.* 2005). However, other factors (Tay *et al.* 2005b) such as amount of volumetric shrinkage of the resin sealer, the elastic moduli of the intraradicular dentine, adhesive sealer and root filling material (Alster *et al.* 1992), the contribution of air voids within the sealer in stress relief (Alster *et al.* 1997), the rate of polymerization and gelation time of the resin sealer (Stansbury *et al.* 2005) and the expansion/contraction involved during thermal plasticization of the root filling material make the FEA analysis more complicated. Therefore, in the present study, the effect of shrinkage stresses of resin cements or resin-based sealers on stress distribution was disregarded. This is another limitation of the current study.

Conclusions

Within the limitations of this FEA study,

1. Stress in root dentine and core material in the FEA models in the case of primary, secondary or tertiary monoblocks created by either endodontic materials or by post-core structures increased from the coronal third of the root to its maximum value located at the cervical region and than it decreased.
2. The stresses within the FEA models increased with the increase in the number of adhesive interfaces.
3. Creation of a primary monoblock unit within the root canal either by an endodontic material or with a post-core system can save remaining tooth structure or prevent root fractures.

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