doi:10.1111/j.1365-2591.2008.01383.x

Effects of post system and length on the strain and fracture resistance of root filled bovine teeth

P. C. F. Santos-Filho[1], C. G. Castro[1], G. R. Silva[1], R. E. Campos[1] & C. J. Soares[2]

Departments of [1]Oral Rehabilitation, and [2]Operative Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, Brazil

Abstract

Santos-Filho PCF, Castro CG, Silva GR, Campos RE, Soares CJ. Effects of post system and length on the strain and fracture resistance of root filled bovine teeth. *International Endodontic Journal*, **41**, 493–501, 2008.

Aim To investigate *ex vivo* the effects of different post systems and lengths on the strain and fracture resistance of root-filled teeth.

Methodology One hundred and thirty-five bovine incisors were sectioned 15 mm from their apices, root-filled and divided into three groups ($n = 45$): fibreglass post; prefabricated steel post; cast post and core. Each group was divided into three subgroups ($n = 15$) according to the post length: 5.0 mm; 7.5 mm; 10.0 mm. All teeth were restored with metal crowns. For strain-gauge measurement, two strain gauges per sample were used. The fracture resistance (N) was measured and the data were analysed with two-way analyses of variance, followed by the Tukey's HSD test ($\alpha = 05$).

Results For all posts, decreased lengths resulted in increased microstrain values. However, the fibreglass posts were associated with lower increases when compared with cast post and cores and prefabricated steel posts, which showed microstrain values two times higher when the post length was 5.0 mm. The two-way analyses of fracture resistance values revealed that post length was statistically significant for the metal posts and not significant for the fibreglass post. The fracture mode analysis indicated that all groups tended to demonstrate root fractures in groups restored with metal posts and resin core fractures in groups restored with fibreglass posts.

Conclusions The cast post and core when the length was 10.0 mm had the highest fracture resistance; however, the fibreglass post was effective with the three post lengths, with higher fracture resistance than metal posts when the length was 5.0 mm.

Keywords: cast post and core, endodontically treated teeth, fibreglass post, fracture resistance, strain gauge.

Received 11 May 2007; accepted 23 November 2007

Introduction

Root filled teeth have a higher risk of biomechanical failure than teeth with vital pulps (Llena-Puy *et al.* 2001, Fennis *et al.* 2002). For decades, restorative modalities for root filled teeth have been the object of much research, with the aim of identifying methods that make the complex root, post and core unit more resistant to the stress of masticatory loads (Boschian Pest *et al.* 2006). The likelihood of a pulpless tooth surviving is directly related to the quantity and quality of the remaining dental tissue (Tjan & Whang 1985). A post was placed in an endeavour to strengthen the tooth (Gutmann 1992, Assif & Gorfil 1994, Cohen *et al.* 1995). However, *ex vivo* (Lovdahl & Nicholls 1977,

Correspondence: Carlos José Soares, Faculdade de Odontologia, Universidade Federal de Uberlândia, Área de Dentística e Materiais Odontológicos, Av. Pará no. 1720, Campus Umuarama, Bloco 2B, Sala 2B-24, CEP 38405-902 Uberlândia, Minas Gerais, Brazil (Tel.:+55 34 32182255; fax: +55 34 32182279; e-mail: carlosjsoares@umuarama.ufu.br).

Guzy & Nicholls 1979, Trope *et al.* 1985, Sorensen & Engelman 1990) and *in vivo* (Sorensen & Martinoff 1984) studies have demonstrated that posts do not reinforce root filled teeth. Moreover, some authors noted that posts may interfere with the mechanical resistance of teeth, increasing the risk of damage to residual tooth structure (Mannocci *et al.* 1999, 2005, Akkayan & Gulmez 2002, Naumann *et al.* 2005, Zarone *et al.* 2006). The main purpose of a post is to provide retention for the core material when there is insufficient remaining clinical crown (Lovdahl & Nicholls 1977, Guzy & Nicholls 1979, Sorensen & Martinoff 1984, Trope *et al.* 1985, Sorensen & Engelman 1990,). The quantity of coronal and root dentine that remains after root canal treatment and post space preparation plays an important role in the longevity of the tooth and restoration (Zhi-Yue & Yu-Xing 2003, Kishen *et al.* 2004). Over-preparing the canal space for a large post or inserting it too deeply can diminish resistance of the tooth to fracture, or affect the apical seal (Guzy & Nicholls 1979, Trope *et al.* 1985, Kvist *et al.* 1989, Ravanshad & Torabinejad 1992, Assif & Gorfil 1994, Boschian Pest *et al.* 2006).

When restoring root filled teeth, clinicians are increasingly opting for materials that have an elastic modulus similar to that of dentine (Peters *et al.* 1983), that are capable of creating homogenous stress distribution and decrease catastrophic root fracture (Ravanshad & Torabinejad 1992, Heydecke *et al.* 2002). Many factors, such as length, diameter, design and post material can influence the biomechanical behaviour of root filled teeth by modifying stress distribution (Assif *et al.* 1989, Barjau-Escribano *et al.* 2006) and fracture resistance (Standlee *et al.* 1972, King & Setchell 1990, Purton & Love 1996, Fernandes & Dessai 2001, Nissan *et al.* 2001, Braga *et al.* 2006). Some reports suggest that the correct post length should be the length of the crown or two-thirds the length of the remaining root (Abdullah *et al.* 1974, Trabert *et al.* 1978, Standlee *et al.* 1980, Sokol 1984, Holmes *et al.* 1996). These statements were related to cast metal posts, which have a high elastic modulus and only frictional retention in the root canal. However, these statements have been transferred to the use of prefabricated metal posts and fibre posts, without taking into consideration the different mechanical properties, and the capacity shown by some of these intra-radicular posts of bonding to dentine, with the use of adhesive systems and resin cements.

The aim of this laboratory study was to compare the root strain and fracture resistance of root filled teeth restored with different post systems and post lengths. Two hypotheses were tested: (i) post system influences the strain, fracture resistance and fracture mode of root-filled teeth; (ii). shorter post lengths increase the root strain and decrease the fracture resistance of root-filled teeth.

Material and methods

One hundred and thirty-five bovine roots of similar size and shape were selected by measuring the buccolingual and mesiodistal widths in millimetres, allowing a maximum deviation of 10% from the determined mean (Soares *et al.* 2006). The teeth were stored in 0.2% thymol solution (Pharmacia Biopharma Ltda., Uberlândia, Brazil). The soft tissue deposits were removed with a hand scaler (SS White Duflex, Rio de Janeiro, Brazil), and the teeth were cleaned using a rubber cup and fine pumice water slurry. The coronal portion of each tooth was sectioned 15.0 mm coronally from the root apex, using a diamond double-faced disk (KG Sorensen, Barueri, SP, Brazil) in a slow-speed handpiece, cooled with air/water spray.

Root canals were prepared throughout their length with Gates–Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) burs 2 and 3, with 4 being used only in the cervical third of the root canal. The canals were irrigated with 1% sodium hypochlorite solution (Asfer, Industrial Química, São Paulo, Brazil). Each canal was filled by lateral compaction using gutta-percha points (Dentsply Maillefer) and sealer (Sealer 26; Dentsply, Imp. Indústria e Comércio Ltda, Petrópolis, RJ, Brazil). The roots were randomly divided into three groups ($n = 45$) as follows: FGP, fibreglass post (Reforpost RX no. 3, Ângelus, Londrina, PR, Brazil); PSP, prefabricated steel post (Reforpost Aço Inox, Ângelus); CPC, cast Ni–Cr alloy post and core (Kromalit, Knebel, Porto Alegre, RS, Brazil). The characteristics of the posts used (Fig. 1) in the study are described in Table 1. The fibreglass post selected had a stainless steel filament along its length. This stainless steel filament only improves the post localization in radiography to verify its position and length in the canal. Each group was divided into three subgroups ($n = 15$) according to the post length: PL5, 5.0 mm; PL7.5, 7.5 mm; PL10, 10.0 mm. The gutta-percha was removed with hot pluggers (SS White Duflex) to the appropriate length in each group. Post-preparations were completed with a No. 5 reamer (Largo; Dentsply). The roots were covered with a 0.3-mm layer of a polyether impression material (Impregum F; 3M Espe,

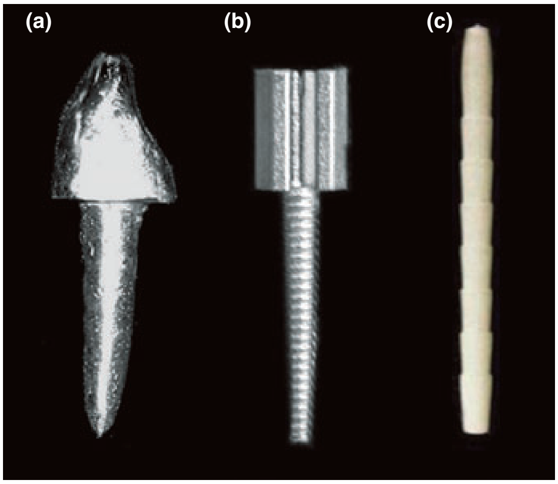

Figure 1 Post types used: (a) cast post and core, (b) prefabricated steel post, (c) fibreglass post.

St Paul, MI, USA) to simulate the periodontal ligament, and embedded in a polystyrene resin (Cristal, Piracicaba, Sao Paulo, Brazil) up to 4 mm below the cervical limit to simulate the alveolar bone (Soares *et al.* 2005).

A direct technique was used to fabricate the cast post and core patterns in acrylic resin (Duralay; Reliance Dental, Worth, IL, USA). A 6.0-mm-high pre-manufactured polycarbonate pattern (Nucleojet; Ângelus, Londrina, PR, Brazil) was used to standardize the coronal portion of the cast metal core. A Ni–Cr alloy

Table 1 Characteristics of the posts used

Post type	Composition	Cervical diameter	Manufacturer
CPC	Ni–Cr alloy	2.0 mm	Knebel
PSP	Stainless steel	1.5 mm	Ângelus
FGP	85% glass fibre 15% epoxi resin 0.2 mm stainless steel filament	1.5 mm	Ângelus

(Kromalit; Knebel, Porto Alegre, RS, Brazil) was used to cast the post-and-core patterns. All posts were cemented following the same protocol. The canals were etched with 37% phosphoric acid (Dentsply, Petrópolis, RJ, Brazil) for 15 s, washed and dried with absorbent paper tips (Dentsply, Petrópolis). Two consecutive layers of the primer (Adper Scotchbond Multi Purpose, 3M-ESPE) were applied using a microbrush, gently air dried after 20 s, and followed by the application of the adhesive (Adper Scotchbond Multi Purpose; 3M-ESPE). Excess adhesive was removed from the canal using a clean microbrush. Light activation was performed for 20 s on the root face, parallel to the long axis of the root, using a halogen light unit with intensity of 800 mW cm^{-2} (XL 3000; 3M ESPE). The post was cleaned with 70% alcohol in a single application using a microbrush, and after drying a silane agent was applied (Silano, Ângelus). The self-curing resin cement (Cement Post, Ângelus) was manipulated in accordance with the manufacturer's instructions, introduced into the canal with a lentulo spiral drill (Dentsply Malleiffer) in a low-speed handpiece. Cement was placed on the post and the post was seated under a constant load of 500 g per 5 min. Excess cement was removed after 1 min. The composite resin cores were standardized using an acetate matrix constructed in a vacuum plasticizer using the CPC as the standard and a composite resin (Filtek Z250; 3M-ESPE). An incremental technique was used to place composite resin, by applying five increments, each requiring 40 s of photo-activation, to complete the coronal core. A photo-activation unit (XL 3000; 3M ESPE) was used to light photo-activate the composite resin specimens, with the light tip positioned 1 cm from the specimens at the top of the core.

All specimens were prepared with a diamond rotary cutting instrument (No. 3215; KG Sorensen, Barueri, SP, Brazil) in a high-speed handpiece with water spray (Super Torque 625 Autofix; KaVo do Brazil Ind Com Ltd, Joinville, SC, Brazil). Specimens were prepared to receive complete crowns with 1.5 mm reduction and 2.0 mm ferrule. An impression of the specimens was made using a polyether impression material (Impregum F; 3M Espe) and the impressions were poured with Type IV stone (Durone IV; Dentsply). Wax patterns were formed using a silicone impression material (Aerojet, São Paulo, Brazil) mould, made in the shape of a composite resin central incisor crown. This mould was used to fabricate all the wax crown patterns. A standardized notch was placed across the palatal surface of each crown 3 mm from the incisal edge for load application in mechanical tests. Wax (Degussa, Hanau, Germany) was then poured into the impression and the tooth was inserted in it. After the wax cooled, the impression was removed and the margins were perfected. The wax patterns were cast in a Ni–Cr alloy (Kromalit; Knebel). Crowns were luted to the teeth following the same protocol as for post fixation.

The strain gauges PA-06-060BG-350LEN (Excel Sensores, SP, Brazil) had an internal electrical resistance of 350 Ω and a grid size of 4.2 mm^2. The strain gauges were attached to five specimens of each group, with cyanoacrylate cement (Super Bonder; Loctite, Gulph Mills, PA, USA) 1 mm away from the cervical margin of the metal crown of external root surface. Two strain gauges were attached to each specimen, one being on the buccal surface, placed parallel to the root long axis and the other on the proximal surface, placed perpendicular to the long axis of the root (Fig. 2). Each specimen was connected to another tooth outside of the analysis process to compensate for dimensional alterations because of temperature and then the strain gauges wires were connected to the data acquisition device (ADS0500IP, Lynx, SP, Brazil). Each specimen was placed in a custom apparatus that allowed the specimen to be positioned at 45° to the buccal/lingual long axis (Moyers 1973). The specimens were subjected to loading at this orientation in a universal testing machine (EMIC DL 2000, São José dos Pinhais, Brazil) until a force of 100 N was achieved (Yoldas *et al.* 2005). The data were transferred to a computer that used specific acquisition, signal transformation and data analysis software (AQDADOS 7.02 and AQANALISYS; Lynx). The strain values were evaluated statistically by one-way ANOVA and Tukey's *post hoc* test to make comparisons amongst the groups.

A water circulation device (Federal University of Uberlândia, Uberlândia, Minas Gerais, Brazil) was constructed to standardize temperature and moisture during the fracture resistance test (Fig. 3). This device consists of an acrylic cylinder 150 mm in diameter and 200 mm high, fixed on a steel base with two water circulation pathways. This device was linked to a water receptacle with a continuous water bombardment system and digital heater (Quimis, São Paulo, Brazil). Next, the temperature was standardized at 37 °C and 100% of humidity.

The teeth were subjected to tangential compressive loading with a metal knife blade tip at a cross-head speed of 0.5 mm min^{-1} in a universal testing machine (EMIC DL 2000). The force required (N) to cause fracture was recorded by a 5-kN load cell hardwired to software (TESC; EMIC), which was able to detect any sudden load drop during compression. Fracture resistance data were analysed with a two-way ANOVA (3 × 3) and the Tukey's honestly significant difference (HSD) test. For all tests, groups were considered

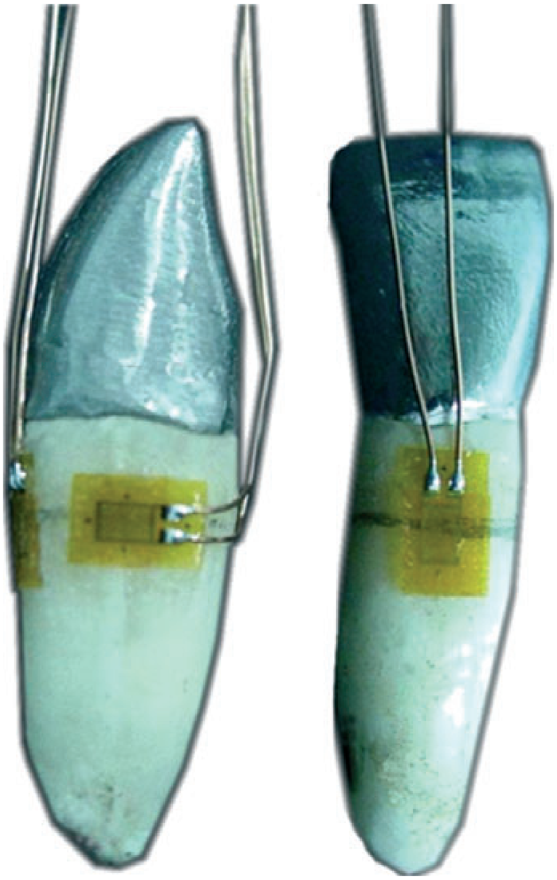

Figure 2 Strain gauges fixed on the buccal and proximal surfaces of each specimen.

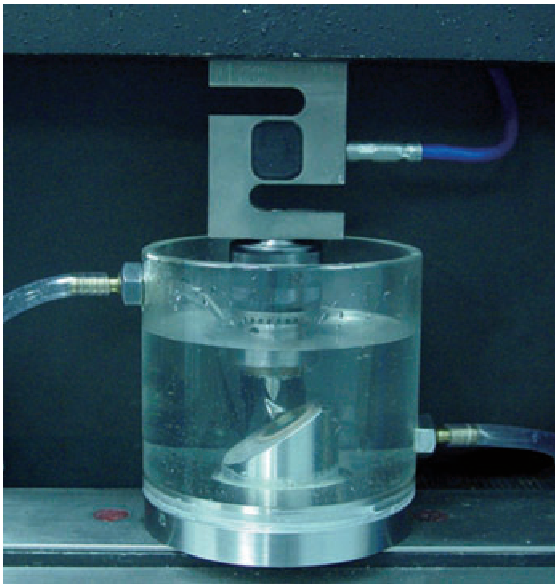

Figure 3 Device with 37 °C water circulation used in the fracture resistance test.

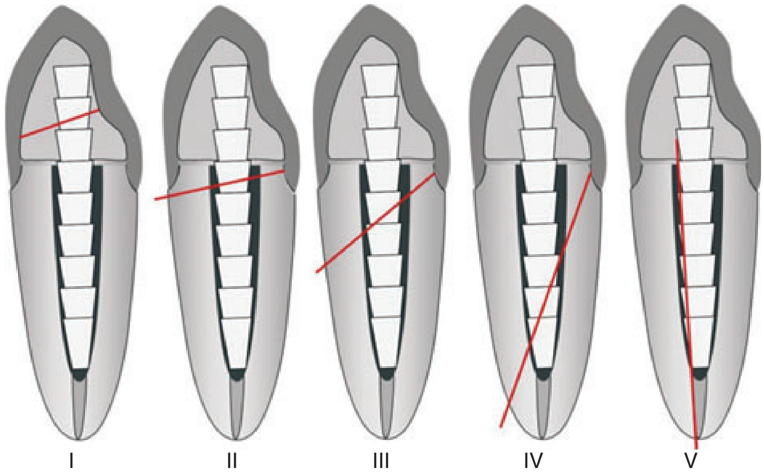

Figure 4 Schematic illustration of the fracture mode classification.

statistically different at α = .05. The fractured specimens were evaluated to determine fracture modes using a modified classification system based on the classification system proposed by Zhi-Yue & Yu-Xing (2003) (Fig. 4): (I) resin core or post fracture, (II) cervical root fracture, (III) mid root fracture, (IV) apical root fracture, (V) vertical root fracture.

Results

Two-way ANOVA revealed that there were significant differences in fracture resistance values for the interaction between post system and post length. The Tukey's test was applied to determine the significance of the interaction of the two factors and indicated that the decreased post length resulted in lower fracture resistance only in metal posts, but with no influence on fibreglass fracture resistance values (Table 2). The fracture mode analysis (Table 3) indicated that all groups tended to demonstrate root fractures in metal posts restored groups but resin core fractures in fibreglass restored groups.

Table 2 Mean values of fracture resistance and SD (N) and statistical categories defined by the Tukey's test (n = 15)

	Post length		
Post type	10.0 mm	7.5 mm	5.0 mm
CPC	769.85 (68.5)^{Aa}	540.01 (86.2)^{Bab}	399.23 (90.0)^{cb}
PSP	698.76 (96.8)^{Aab}	502.77 (134.7)^{Bb}	390.16 (94.6)^{cb}
FGP	618.46 (177.5)^{Ab}	615.76 (127.7)^{Aa}	607.18 (139.7)^{Aa}

Different letters indicate significant differences ($P < 0.05$) verified by two-way ANOVA and Tukey's tests ($P < 0.05$). Capital letters were used to compare groups in the horizontal lines and lower case letters were used to compare groups in the vertical lines.

Table 3 Fracture mode distribution of groups tested (n = 15)

		Fracture mode distribution				
Post type	Post length	I	II	III	IV	V
CPC	5.0 mm	–	11	1	–	3
	7.5 mm	–	–	9	2	4
	10.0 mm	–	–	–	–	15
PSP	5.0 mm	1	10	1	–	3
	7.5 mm	4	–	8	1	2
	10.0 mm	5	–	–	2	8
FGP	5.0 mm	15	–	–	–	–
	7.5 mm	15	–	–	–	–
	10.0 mm	14	1	–	–	–

The mean strain values of the groups are shown in Table 4. When post length decreased, all groups revealed increased microstrain values on the buccal surface. However, fibreglass posts had lower increases when compared with cast posts and cores and prefabricated steel posts, which showed microstrain values two times higher when the post length was 5.0 mm. At the proximal surface, fibreglass posts had low strain for all post lengths, whilst cast posts and cores and prefabricated steel posts behaved as observed for the buccal surface.

Discussion

The first hypothesis was accepted; the post system had an influence on strain, fracture resistance and fracture

Table 4 Mean values of the microstrains (μS) and SD of the buccal surface (B) and proximal surface (P) (n = 5)

	Post length					
	10.0 mm		7.5 mm		5.0 mm	
Post type	B	*P*	B	*P*	B	*P*
CPC	335 (38.07)	90 (25.08)	460 (147.47)	130 (90.82)	730 (139.64)	200 (93.54)
PSP	700 (100.00)	106 (43.93)	960 (181.65)	138 (44.38)	1360 (114.01)	216 (56.83)
FGP	780 (228.03)	78 (22.80)	840 (151.65)	80 (15.81)	880 (277.48)	80 (15.81)

mode of root filled teeth. The second hypothesis was partially accepted; decreased post length increased the root strain and decreased the fracture resistance only of the root filled teeth restored with metal posts.

In the biomechanical analysis of tooth structures and restorative materials, destructive mechanical tests used to determine fracture resistance are important means of analyzing tooth behaviour in situations of concentrated and high intensity load application. They do, however, present limitations when obtaining information on the internal behaviour of the tooth–restoration complex. Therefore, it is important to associate destructive tests with nondestructive methodologies, such as strain gauge measurement, for root strain analysis and its relation with fracture resistance and fracture mode. This occurs because transmission of strain energy to the crack tip, supplies energy for crack propagation and the speed at which the crack is fed with energy will depend upon the rate of change in shape of the material adjacent to the crack. Consequently, the fracture resistance will be increased by any mechanism that increases the amount of energy required to propagate the primary crack (Kishen *et al.* 2004).

There was a definite correlation between post material and root fractures. The post material should have the same modulus of elasticity as root dentine to distribute the applied forces evenly along the length of the post and root (Assif *et al.* 1989, King & Setchell 1990, Barjau-Escribano *et al.* 2006). It was not possible to use teeth restored without a post as a control group in this study. It was not possible because bovine roots employment required a post to retain the restoration. According to the results of this study, when comparing the subgroups with 10.0 mm post length, the cast post and core group had the lowest mean strain values and the highest fracture resistance values, being statistically different from the fibreglass post group. However, the fracture mode of the cast posts and cores and prefabricated steel posts was less favourable because of the occurrence of root fractures.

The statement that when a system with components of different rigidity is loaded, the more rigid component is capable of resisting greater forces without distortion (Fernandes & Dessai 2001) could explain the high incidence of root fractures in metal post restored roots, when compared with nonmetal post restored roots, observed in laboratory studies (Mannocci *et al.* 1999) and clinical trial studies (Mannocci *et al.* 2005, Naumann *et al.* 2005). This occurs because roots restored with a material that has a high modulus of elasticity becomes more rigid as a result of internal stress concentrations, and consequently low strains. Thus, these roots are more resistant to fracture and do not show post or core failure; however, these roots show more root fractures, which is clinically relevant when using decreased post lengths.

Another important factor in post selection is post length. The length of the post influences stress distribution in the root and thereby affects its resistance to fracture. It has been noted that the success rate of root filled teeth increases when the length of the post is equal to or greater than the crown length (Standlee *et al.* 1980, Sokol 1984). A higher failure rate is seen when the post length is too short (Holmes *et al.* 1996). Trabert *et al.* (1978) reported that the length of metal posts and fracture resistance are directly proportional. Standlee *et al.* (1972) observed lower stress concentrations when the length of metal posts increased: post length equivalent to three-quarters of root length provided greater rigidity and reduced root bending when compared with post lengths equivalent to half and quarter of root length. The results obtained in this study reflect the importance of increasing the length of metal posts. The strain values of cast posts and cores and prefabricated steel posts increased when post length decreased and this was observed on the buccal and proximal surfaces. Strain values on proximal surfaces seem to be particularly more important when one compares fracture resistance and fracture mode. The strain gauges fixed on the proximal surface, placed perpendicular to the root long axis measured the tensile strain of the proximal surface. This tensile strain starts inside the root canal and can spread through the cracks leading to catastrophic fracture of the structure. In the fibreglass post group, a decrease in post length did not influence the strain values on the buccal and proximal surfaces, probably because of the similarity of the mechanical properties between fibreglass post and dentine. The strain values were correlated with the fracture resistance and fracture mode. As post length decreased, a decrease in cast post and core and prefabricated steel post fracture resistance values was observed, whilst the fibreglass post fracture resistance values remained constant. When the post length was 5.0 mm it was noted that fibreglass post fracture resistance value was statistically higher than those of cast post and core and prefabricated steel post.

All the cast post and core specimens suffered root fractures. The prefabricated steel post specimens had more root fractures than resin core fractures, mainly when the post length was 5.0 mm, where almost 95% were fractured. The fibreglass post group revealed resin core or post fractures for all post lengths, with the possibility of a replacement restoration being placed.

The stability of fibreglass post strain and fracture resistance values for all post lengths studied can be justified by its low elastic modulus similar to that of dentine. This allowed the restored root strain to occur as it did in sound teeth with the stress distribution along the restored tooth structures (Zarone *et al.* 2006). Low elastic modulus materials, such as glass-fibre posts and composite resins follow the natural flexural movements of the tooth, reducing stress arising at the interfaces, enabling the restored system to mimic the mechanical behaviour of a natural tooth (Zarone *et al.* 2006). High elastic modulus materials like metal posts significantly withstand deformation, generating high stress concentrations at the interfaces. As a result, such materials negatively modify the biomechanical behaviour of the restorative system (Zarone *et al.* 2006). Torbjorner & Fransson (2004) summarized the post material choice as follows: either a post with low modulus and an early but hopefully reparable technical failure, or a post with high modulus, technical failure after a long time in function and/or at high stress levels, and more frequently irreparable failures.

Other important factor related to decrease in post length is the reduction of retention. However, as they are adhesively luted into the canal, posts that are not as deeply inserted still provide similar retention values, allowing clinicians to be more conservative (Nissan *et al.* 2001, Braga *et al.* 2006). This can be justified by the fact that when a light-activated bond system is used in a root canal, the post preparation depth is higher than polymerization depth achieved with the most of the light curing units, negatively influencing bonding in the apical third of the root (Hansen & Asmussen 1997). Consequently, further studies are required to reach conclusions about the influence on bonding in the apical third of the root on nonmetal post retention.

This study has some limitations such as lack of specimen ageing and fatiguing. Thermal and mechanical cyclic loading are an interesting feature when analysing root-filled teeth. It is therefore suggested for future studies that cyclic loading be used, such as finite element analysis for stress distribution analysis and the relationship with strain gauge tests and fracture resistance.

Conclusions

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

1. Post length is a significant factor only for metal posts, and has no influence on the biomechanical behaviour of the fibreglass post.

2. When the post length was 10.0 mm, the cast post and core had the highest fracture resistance.

3. Fibreglass posts had the same effectiveness with all post lengths studied and had greater fracture resistance than cast post and core when the post length was 5.0 mm.

4. Metal posts resulted in an irreparable fracture mode with root fractures whilst the fibreglass posts had reparable fractures with resin core or post fractures.

Acknowledgements

The authors are indebted to LIPO/UFU/Uberlândia/Brazil for the physical space offered to conduct this experiment; to FAPEMIG (grant number: CDS 1355/05) for the financial support throughout the research and to Professor Simamoto-Júnior PC/ESTES/UFU for the prosthetic laboratory support offered to construct the cast posts and crowns.

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