International Endodontic Journal

doi:10.1111/j.1365-2591.2010.01807.x

Influence of post system and remaining coronal tooth tissue on biomechanical behaviour of root filled molar teeth

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Abstract

Santana FR, Castro CG, Simamoto-Júnior PC, Soares PV, Quagliatto PS, Estrela C, Soares CJ. Influence of post system and remaining coronal tooth tissue on biomechanical behaviour of root filled molar teeth. *International Endodontic Journal*, **44**, 386–394, 2011.

Aim To investigate *ex vivo* the influence of post system and amount of remaining coronal tooth tissue on the fracture resistance, fracture mode and strain of root filled molar teeth.

Methodology Seventy mandibular human molar teeth were divided into seven groups (n = 10), one control (sound teeth) and six experimental groups resulting from the interaction between the two study factors: post system (Pa, post absence; Gfp, glass fibre post; Cmp, cast Ni–Cr alloy post and core) and amount of remaining coronal tooth tissue (Fe, 2 mm of ferrule; NFe, no ferrule). Teeth in the experimental groups were restored with metal crowns. For the strain gauge test, two strain gauges per sample were attached on the buccal and proximal root surfaces, and the samples of each group (n = 5) were submitted to a load of 0–100 N. Fracture resistance (N) was assessed in a mechanical testing device (n = 10). Strain gauge and fracture resistance data were analysed by two-way ANOVA (3 × 2) followed by the Tukey's HSD and Duncan's test (α = 0.05). The failure mode was evaluated using an optical stereomicroscope and classified according to the location of the failure.

Results The absence of ferrule was associated with lower fracture resistance regardless of the post system. Groups restored with glass fibre post and cast Ni–Cr alloy post and core had similar fracture resistance and higher values than groups without posts, regardless of the remaining coronal tooth tissue. Teeth with no ferrule and cast Ni–Cr alloy post and core resulted in catastrophic fractures and those with no ferrule and glass fibre post or no ferrule and post absence resulted in restorable failures. Buccal strain was higher in sound teeth and lower in teeth without posts. Glass fibre post insertion decreased the buccal strain compared to the teeth with ferrule and absence of post.

Conclusions Two millimetre of ferrule had a significant influence on cusp strain, fracture resistance and failure mode. The glass fibre post was as effective as the cast Ni–Cr alloy post and core in the restoration of root filled molars regardless of the remaining tooth tissue. Absence of a post decreased the fracture resistance and increased the cusp strain.

Keywords: cast post and core, fracture resistance, glass fibre post, root filled molar, strain gauge test.

Received 3 April 2010; accepted 11 September 2010

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Introduction

Root filled teeth are considered to have a higher prevalence of fracture because of their inherently poor structural integrity as a result of pre-existing caries or tooth preparation (Burke 1992, Assif & Gorfil 1994, Morgano *et al.* 2004, Schwartz & Robbins 2004, Salameh *et al.* 2006, Rodrigues *et al.* 2010). Loss of the pulp chamber roof as a result of the access preparation and the loss of root dentine as a result of coronal instrumentation (Burke 1992, Morgano *et al.* 2004, Tang *et al.* 2010, Rodrigues *et al.* 2010) together with alteration of the physical and mechanical properties of dentine owing to endodontic procedures (Burke 1992, Schwartz & Robbins 2004, Soares *et al.* 2007, Tang *et al.* 2010) are further factors that are likely to influence the fracture resistance of such teeth.

The fracture potential of root filled teeth has been studied extensively; however, no definite causal relationship between fracture and the type of restoration has been established, and controversies remain about which materials or techniques are best for their restoration (Salameh *et al.* 2006, Rodrigues *et al.* 2010). Thus, the restoration of such teeth is a challenge for restorative dentistry, because often, these teeth have insufficient coronal structure to retain the restorative material. On occasions, they require the use of a post to provide sufficient retention for the core (Morgano 1996, Morgano & Brackett 1999, Morgano *et al.* 2004, Cheung 2005, Tan *et al.* 2005, Tang *et al.* 2010). Otherwise, sufficient retention for the restoration can be provided by the dentine walls of the pulp chamber (Morgano 1996, Morgano & Brackett 1999, Morgano *et al.* 2004, Schwartz & Robbins 2004, Cheung 2005).

Cast posts have good resistance and adaptation to root canals that results in an uniform thickness of cement (Cheung 2005). However, their disadvantages include inhomogeneous stress distribution (Assif & Gorfil 1994, Joshi *et al.* 2001, Tokasvul *et al.* 2006) and aesthetic and biological problems owing to microleakage and corrosion (Cheung 2005, Salameh *et al.* 2008). Glass fibre posts improve stress distribution, as their elastic modulus closely matches that of dentine (Joshi *et al.* 2001, Akkayan & Gülmez 2002, Barjau-Escribano *et al.* 2006, Salameh *et al.* 2008). In addition, they might, through effective adhesion to the resin cement, bond to the tooth structure (Malferrari *et al.* 2003, Prisco *et al.* 2003, Cheung 2005). Therefore, this adhesive complex is capable of mimicking the biomechanical behaviour of sound teeth (Malferrari *et al.* 2003, Zarone *et al.* 2006, Santos-Filho *et al.* 2008). In addition, these systems are relatively simple to use and consume less clinical time (Malferrari *et al.* 2003, Cheung 2005).

The amount of coronal and root dentine that remains after root canal instrumentation and post space preparation plays an important role in the longevity of the tooth and restoration (Zhi-Yue & Yu-Xing 2003). It is generally accepted that when restoring a root filled tooth with a post/core and crown, a ferrule design should be incorporated (Assif & Gorfil 1994, Morgano 1996, Morgano & Brackett 1999, Morgano *et al.* 2004, Ichim *et al.* 2006, Tang *et al.* 2010). The ferrule design incorporates a crown with a 360° collar that surrounds the perimeter of the prepared parallel dentine walls and extends cervically to the shoulder of the tooth preparation (Morgano & Brackett 1999, Morgano *et al.* 2004, Schwartz & Robbins 2004, Ichim *et al.* 2006).

Post type and presence of ferrule are factors that significantly affect the biomechanical behaviour of root filled teeth (Sorensen & Engelman 1990, Libman & Nicholls 1995, Zhi-Yue & Yu-Xing 2003, Akkayan 2004, Tan *et al.* 2005, Ichim *et al.* 2006, Pereira *et al.* 2006, 2009). However, no previous studies have investigated the combined effect of these factors in root filled molars. Therefore, the aim of this laboratory study was to investigate the effect of the post system and the amount of remaining coronal tooth tissue on the strain, fracture resistance and fracture mode of root filled mandibular molar teeth. The hypothesis tested was that the post system and the amount of remaining coronal tooth influence the strain, fracture resistance and fracture mode of root filled mandibular molars.

Material and methods

Specimen preparation

Seventy human mandibular first molar teeth, extracted for periodontal reasons, free from cracks and defects were selected (approved by the Federal University of Uberlândia Ethics Committee, No. 072/2008). Teeth of similar size and shape were selected by root dimensions after measuring the height and buccolingual and mesiodistal widths in millimetres, allowing a maximum deviation of 10% from the determined mean. Soft tissue deposits were removed with a hand scaler (SS White Duflex, Rio de Janeiro, RJ, Brazil), and teeth were cleaned using a rubber cup and fine pumice water slurry and then stored in 0.2% thymol solution (Pharmacia Biopharma Ltd., Uberlândia, MG, Brazil). The teeth were divided into seven groups ($n = 10$), including the control group with sound teeth, which received no treatment (Cont), and six experimental groups defined by the two factors investigated (Fig. 1): post system (Pa, post absence; Gfp, glass fibre post;

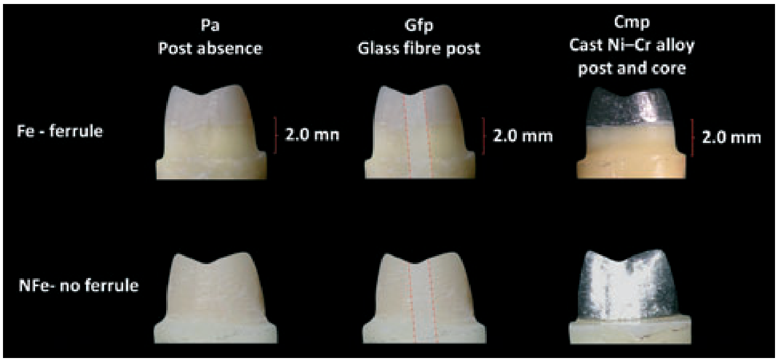

Figure 1 Tooth preparation for all groups defined by two study factors: (a) post system (Pa, post absence; Gfp, glass fibre post; Cmp, cast Ni–Cr alloy post and core); (b) Level of coronal tooth remaining (Fe, 2 mm of ferrule; NFe, no ferrule).

Cmp, cast Ni–Cr alloy post and core) and amount of remaining coronal tooth tissue (Fe, 2 mm of ferrule; NFe, no ferrule). For groups with Fe, teeth had their crowns reduced with grit silicon carbide paper (3M-Espe, St. Paul, MN, USA) to a level 2.0 mm coronal to the dentine–enamel junction (CEJ) under constant water irrigation, and for groups without remaining of coronal tooth tissue (NFe), the crown was completely removed to the level of the CEJ.

Root canals that would receive posts were instrumented with a size 80 master apical file, and the root canals that did not received posts were instrumented with a size 40 master apical file (K-file; Dentsply Maillefer, Ballaigues, Switzerland). The irrigants used were 1.0% sodium hypochlorite (Cloro Rio 1.0%, São José do Rio Preto, SP, Brazil) with 0.9% saline solution (Indústria Farmacêutica Basa, Caxias do Sul, RS, Brazil) as the final rinse. The root canals were filled with gutta-percha points and calcium-hydroxide-based cement (Sealer Dentsply, Dentsply Petrópolis, RJ, Brazil).

Post space was obtained initially with a heated instrument, and the residual gutta-percha was then removed with a Gates-Glidden bur (No. 2, Dentsply Malleifer) in the distal root canal (Schwartz & Robbins 2004, Cheung 2005, Tang *et al.* 2010). Two thirds of the root canal length was prepared, standardizing the post space to 10.0 m and preserving 5.0 mm of root filling at the apex. Root canal walls were then enlarged with calibrated bur No. 2 corresponding to the glass fibre conical post (coronal 1.4 mm in diameter and apical 0.9 mm in diameter – Exacto No. 2; Angelus, Londrina, PR, Brazil). The post space preparations were the same for all groups. The mesial root canals were not prepared for posts, but the gutta-percha was removed with heated instrument to a depth of 1.0 mm.

Roots were embedded in self-polymerizing polystyrene resin (AM 190 Resin; Aerojet, São Paulo, SP, Brazil) to 2.0 mm below the coronal level. The periodontal ligament was simulated using a polyether-based impression material (Impregum Soft; 3M-ESPE, Saint Paul, MN, USA). To carry out this procedure, root surfaces were dipped into molten wax (Epoxiglass, Diadema, SP, Brazil) up to 2.0 mm apically to the coronal surface, resulting in a 0.2- to 0.3-mm-thick wax layer. A radiographic film with a centralized circular hole was used to stabilize teeth for the embedding procedure. This assembly was placed with the crown faced down into a hole in a wooden board leaving the root in a vertical position perpendicular to the supporting radiographic film. Then, a plastic cylinder (Tigre, Rio Claro, SP, Brazil), 20 mm in height and 22 mm in diameter, was placed over the root and fixed in position with cyanoacrylate-based adhesive (Super Bonder; Loctite, Itapevi, SP, Brazil) and wax. The polystyrene resin was manipulated according to manufacturers' instructions and inserted into the cylinder. After resin polymerization, the teeth were removed from the cylinder and the wax was removed from the both root surface and resin cylinder. The polyether material was placed in the resin cylinder, the tooth was inserted in the cylinder, and the excess polyether material was removed with a scalpel blade (Soares *et al.* 2005).

Post and core, and crown restoration

Prefabricated polycarbonate patterns were used for the cast post and core (Pinjet; Angelus). Reline of patterns was carried out using polymerizing acrylic resin in the root canal (Duralay; Reliance Dental, Worth, IL, USA) until passive retention was achieved. To reproduce a standardized coronal core shape and dimension, an acrylic resin pattern was obtained from an additional sound molar prepared for a veneer crown with diamond rotary cutting instruments (No. 1014 and No. 3215; KG Sorensen, Barueri, SP, Brazil) in a high-speed handpiece with water spray (KaVo, Joinville, SC, Brazil) with the following standardized dimensions: 5.0 mm cervico-occlusal height on the buccal face; 4.0 mm cervico-occlusal height on the lingual face; 8.5 mm mesiodistal width; 7.6 mm buccolingual width. An impression of the preparation was taken using a polyether impression material (Impregum Soft; 3M-ESPE), and the impression was poured with acrylic resin (Duralay; Reliance Dental) producing a replica of the standardized core in acrylic resin. For the groups with a ferrule and cast post, owing to the 2.0 mm of remaining coronal tooth tissue, the standardized resin cores were made with a 3.0 mm cervico-occlusal height on the buccal face and 2 mm on the lingual face. The patterns were invested cast in nickel–chrome alloy (Ni–Cr alloy, Kromalit; Knebel, Porto Alegre, RS, Brazil).

All posts were cemented with self-adhesive resin cement (RelyX U100; 3M-ESPE). Before cementation, cast post and cores were sandblasted with aluminium oxide particles (50 μm) under 2 bar pressure for 10 s (Microblaster; Bio-Art, Sao Carlos, SP, Brazil) and cleaned in distilled water under ultrasonic vibration. Fibreglass posts were cleaned with 70% alcohol, then in a single application using a microbrush, and after drying, a silane agent was applied (Silano; Angelus). The self-adhesive resin cement (RelyX U100; 3M-ESPE) was manipulated in accordance with the manufacturer's instructions, introduced into the canal with K-file and placed on the post. The post was seated under a constant load of 500 g per 5 min. Excess cement was removed after 1 min. After 5 min, the resin cement was light-cured on each coronal root surface (buccal, lingual, occlusal) for 40 s with 1200 mW cm^{-2} (Radii-Cal; SDI, Bayswater, Australia).

The composite resin cores were standardized using an acetate matrix (Bio-Art) constructed in a vacuum plasticizer (Plastvac P6; Bio-Art) and were identical to the acrylic resin standardized cores used to fabricate the cast post and core patterns. After Gfps cementation, the pulp chamber was etched with 37% phosphoric acid (Acid Gel; Villevie, Joinville, SC, Brazil) for 15 s, rinsed and dried with absorbent paper points. Two applications of a one-bottle adhesive system (Adper Single Bond 2; 3M-ESPE) were applied with an interval of 20 s and light-polymerized for 20 s with 1200 mW cm^{-2} (Radii-Cal; SDI). An incremental technique was used to place the composite resin (Filtek Z350; 3M-ESPE), and each increment was light-polymerized for 20 s (Radii-Cal; SDI). The acetate matrix was used in the insertion of the last composite resin increment to complete the coronal core. In groups that used only composite resin cores, the excess endodontic cement was removed, followed by the surface treatment of the pulp chamber; the core reconstruction was undertaken with the procedures described earlier.

All teeth were prepared with a diamond rotary cutting instrument (No. 3215; KG Sorensen) in a high-speed handpiece with water spray (KaVo). Specimens were prepared to receive complete crowns with 1.5-mm reduction. In groups with a ferrule, vertical walls of 2.0 mm in height remained, allowing the creation of a 2.0-mm ferrule. An impression of the specimens was taken using a polyether impression material (Impregum Soft; 3M-ESPE), and the impressions were poured with type IV stone (Dental Mix IV; PASOM Ind. e Com. de Materiais Odontológicos Ltd., São Paulo, SP, Brazil). Wax patterns were formed using a silicone impression material (Aerojet) mould, made in the shape of a composite resin mandibular molar crown. This mould was used to fabricate all the wax crown patterns. Wax (KOTA Import's, São Paulo, SP, Brazil) was then poured into the impression, and the stone die was inserted in it. After the wax cooled, the impression was removed and the margins were refined. The wax patterns were cast in a Ni–Cr alloy (Kromalit; Knebel). Crowns were luted to teeth following the same protocol as for post fixation.

To measure strain, strain gauges PA-06-038AA-120-LEN (Excel Sensores, Embú, SP, Brazil) with an internal electrical resistance of 120 Ω and a grid size of 1.1 mm^2 were attached to five specimens of each group with cyanoacrylate cement (Super Bonder Loctite; Henkel Ltd., São Paulo, SP, Brazil) on the external root surface of teeth (Soares *et al.* 2008). Two strain gauges were attached to each specimen, one being on the buccal root surface, placed perpendicular to the root long axis, and the other on the proximal root surface placed parallel to the long axis of the root, both were placed 1 mm away from the coronal preparation (Fig. 2a), and connected to a data acquisition device (ADS0500IP; Lynx, São Paulo, Brazil). These points and directions of the strain gauges were determined from preliminary tests that analysed various orientations to better capture the strain signal generated by loading performed in this study.

Each specimen was connected to another tooth outside of the analysis process to compensate temperature fluctuations owing to gauge electrical resistance or local environment. Each specimen was placed in a custom apparatus that allowed the specimen to be

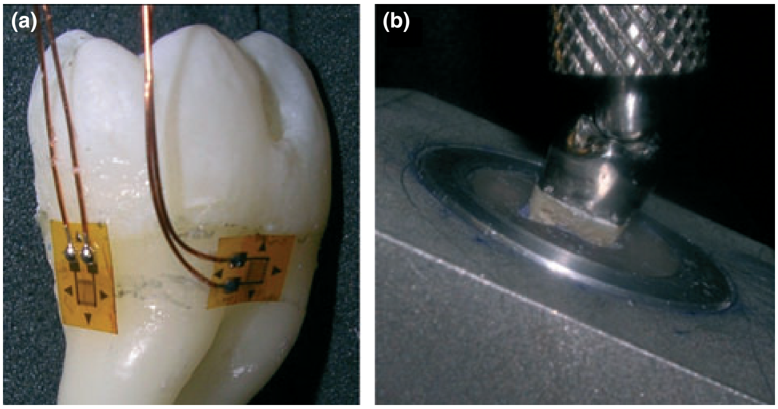

Figure 2 Mechanical tests (a) Strain gauges fixed on the buccal and proximal surfaces of each specimen. (b) Tooth subjected to 25° tangential compressive loading during fracture testing.

positioned at 25° to the buccal/lingual long axis (Langlade 2002). The specimens were submitted to compressive loading at this orientation at a speed of 0.5 mm min^{-1}, using a 6.0-mm steel sphere (Soares *et al.* 2006) in a universal testing machine (EMIC 2000DL, São José dos Pinhais, PR, Brazil), until a force of 100 N was achieved (Santos-Filho *et al.* 2008). 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 two-way ANOVA (7 × 2), being seven experimental groups and two positions of strain measurement, followed by the Duncan's test to make comparisons amongst the groups.

The teeth were subjected to 25° tangential compressive loading (Langlade 2002) with a 6.0-mm steel sphere at a speed of 0.5 mm min^{-1} in a universal testing machine (EMIC 2000DL) until fracture (Soares *et al.* 2006). The force required (N) to cause fracture was recorded by a 10-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 two-way ANOVA (3 × 2), being three posts systems and two levels of coronal tooth remaining, followed by the Tukey's honestly significant difference (HSD) test. For all tests, a statistically significant difference was considered when $\alpha = 0.05$. The fracture specimens were evaluated under an optical stereomicroscope to determine the failure mode according to the location of the failure using the classification system proposed by Santos-Filho *et al.* (2008) adapted to posterior teeth: type I, resin core or post fracture; type II, cervical root fracture; type III, medium root fracture, subtype A, without furcation involvement; subtype B, with furcation involvement; type IV, apical root fracture; type V, vertical root fracture; type VI, enamel or coronal dentine fracture exclusive to control group (Fig. 3).

Results

There were significant differences in fracture resistance values for the amount of remaining coronal tooth ($P < 0.001$) and for post type ($P = 0.002$), but not for the interaction between the two factors ($P = 0.399$). The absence of coronal tooth tissue was associated with lower fracture resistance values regardless of the post system (Table 1). Root filled molars restored with glass fibre posts and cast posts had similar fracture resistance and higher fracture resistance than the teeth restored without posts, regardless of the level of coronal dental remaining (Table 1).

The fracture mode analysis (Table 2) indicated that the control group had predominantly coronal fractures (70% type VI). In groups with a ferrule, teeth restored with cast posts had a 40% prevalence of type III fractures and a 50% prevalence of type V fractures.

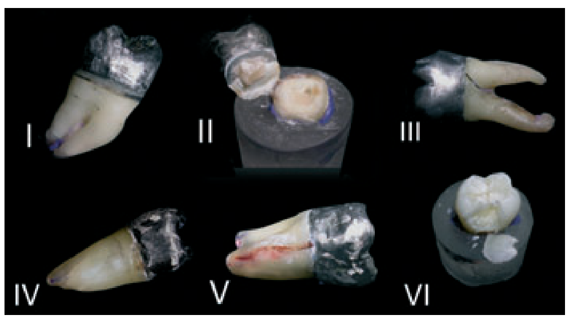

Figure 3 Schematic representation of the failure mode: type I, resin core or post fracture; type II, cervical root fracture; type III, medium root fracture; type IV, apical root fracture; type V, vertical root fracture; type VI, enamel or coronal dentine fracture exclusive to control group.

Table 1 Mean values and standard deviation of fracture resistance (N) and results of Tukey's test ($n = 10$)

	Coronal tooth remaining			
	2 mm		0 mm	
Post system	Fracture resistance	Tukey category*	Fracture resistance	Tukey category*
Cast post	2934.0 (785.9)	Aa	1879.1 (555.6)	Ab
Glass fibre post	2854.2 (642.9)	Aa	2120.0 (589.9)	Ab
Absence of post	2034.9 (680.2)	Ba	1528.3 (534.2)	Bb

*Tukey categories with same letters are not statistically significant from each other ($P < 0.05$). Capital letters were used to compare groups in the vertical lines (post type), and lower case letters were used to compare groups in the horizontal lines (coronal tooth remaining).

Table 2 Failure mode distribution in experimental groups ($n = 10$)

	Failure mode distribution						
			III				
Groups	I	II	A	B	IV	V	VI
Sound	–	3	–	–	–	–	7
Ferrule and cast post	–	–	2	2	1	5	–
Ferrule and glass fibre post	1	2	4	2	1	–	–
Ferrule and absence of a post	1	2	1	3	2	1	–
No ferrule and cast post	1	1	1	–	1	6	–
No ferrule and glass fibre post	9	–	–	1	–	–	–
No ferrule and absence of a post	8	1	–	–	1	–	–

I, resin core or post fracture; II, cervical root fracture; III, medium root fracture, subtype A, without furcation involvement, subtype B, with furcation involvement; IV, apical root fracture; V, vertical root fracture; VI, enamel or coronal dentine fracture (exclusive to control group).

Teeth with glass fibre posts or with without posts had a 60% and 40% prevalence of type III fractures, respectively, with furcation involvement in two teeth with glass fibre post and three teeth without posts. In groups without a ferrule, teeth restored with cast posts had a 60% prevalence of type V fractures, whilst teeth with glass fibre posts or without posts had a prevalence of 90% and 80% of type I fractures, respectively.

The mean strain values of the groups are shown in Table 3. There were significant differences in strain values for the position of strain gauges ($P = 0.003$), experimental group type ($P < 0.001$) and the interaction between the two factors ($P = 0.013$). Sound teeth had higher strain values in the buccal aspect than the other groups. On the buccal aspect, the teeth with a ferrule and no post had significantly lower strain values than the control group and higher strain values than the teeth with no ferrule and glass fibre posts and no ferrule and no post. The teeth with no ferrule and no post had the lowest buccal strain value. In the proximal

Table 3 Mean values of the microstrains (μS) and SD of the buccal and proximal surface, and statistical categories defined by Duncan's test ($n = 5$)

	Buccal		Proximal	
Groups	μS	Tukey category*	μS	Tukey category*
No ferrule and absence of a post	391.6 (98.1)	Aa	279.3 (73.8)	Aa
No ferrule and glass fibre post	447.4 (104.2)	ABa	318.3 (72.1)	Aa
Ferrule and glass fibre post	458.6 (115.7)	ABa	359.5 (43.9)	Aa
Ferrule and cast post	497.7 (103.3)	ABCb	333.2 (76.5)	Aa
No ferrule and cast post	551.1 (114.2)	BCb	331.8 (76.5)	Aa
Ferrule and absence of a post	600.1 (104.1)	Cb	311.1 (49.0)	Aa
Sound teeth	685.6 (105.1)	Db	330.8 (51.4)	Aa

*Tukey categories with same letters are not statistically significant from each other ($P < 0.05$). Capital letters were used to compare groups in the vertical lines (groups), and lower case letters were used to compare groups in the horizontal lines (region analysed).

region, the strain was similar amongst all groups. In the comparison of the strain values obtained in the buccal and proximal regions, the teeth with no ferrule and no post, teeth no ferrule and glass fibre posts and teeth with ferrule and glass fibre posts were statistically similar, and the groups with sound teeth, teeth with a ferrule and no post, teeth no ferrule and cast posts and teeth with a ferrule and cast posts had higher values of strain on the buccal aspect.

Discussion

The hypothesis was supported by the results; the amount of remaining coronal tooth tissue and the post system had an influence on strain, fracture resistance and fracture mode of root filled mandibular molars. The 2.0 mm of remaining coronal tooth resulted in higher fracture resistance than the absence of tooth tissue (Table 1). This parameter has been largely supported in studies that analyse anterior teeth and means that a ferrule increases the fracture resistance of root filled teeth (Sorensen & Engelman 1990, Libman & Nicholls 1995, Zhi-Yue & Yu-Xing 2003, Akkayan 2004, Tan *et al.* 2005, Ichim *et al.* 2006, Pereira *et al.* 2006, 2009). Thus, this study has demonstrated that maintenance of coronal tissue and the creation of a ferrule effect into the design of the crown should apply to mandibular molar teeth.

Stress in root dentine during function is concentrated to the circumference of the tooth, whereas the stress level is lowest within the root canal (Assif & Gorfil 1994, Torbjörner & Fransson 2004). The centre of the root is a neutral area with regard to stress concentration, and thus, no reinforcement is needed in this area. If reinforcement is desired, incorporating a ferrule into the design of the crown, embracing the circumference of the root, protects the root where the maximum forces occur (Torbjörner & Fransson 2004). The ferrule effect also protects the root filled tooth against fracture by counteracting and stresses dissipation by the post effect (Morgano 1996, Zhi-Yue & Yu-Xing 2003), which is directly proportional to the amount of remaining dentine (Tan *et al.* 2005). A larger amount of remaining dentine might create a more stable foundation for the post and core (Tan *et al.* 2005). Moreover, the ferrule can improve the resistance to dynamic occlusal loading, maintain the integrity of the cement seal of the artificial crown (Libman & Nicholls 1995, Zhi-Yue & Yu-Xing 2003) and reduce the potential for stress concentration at the junction of the core and the post (Morgano 1996, Morgano & Brackett 1999, Zhi-Yue & Yu-Xing 2003). All of these considerations might explain the increase in fracture resistance in the groups with a ferrule verified in this study. On the other hand, the predominance of root fractures can be explained by the findings of a previous study that employed finite element analysis in a maxillary incisor model, where the presence of a ferrule created a larger area of palatal dentine under tensile stress, which might be a favourable condition for a crack to develop on the palatal portion of the root eventually leading to an oblique root fracture (Ichim *et al.* 2006).

Conversely, when the ferrule is absent, occlusal forces are resisted exclusively by the post and core, which might eventually fracture; otherwise, vertical root fracture might occur (Morgano 1996, Zhi-Yue & Yu-Xing 2003, Ichim *et al.* 2006) as a function of the lever action of the post inside the root canal. This finding explains the fracture mode observed in teeth with no ferrule and glass fibre posts and teeth with no ferrule and no post that had a predominance of fractures involving the resin core or post (type I) and in teeth with no ferrule and cast posts that had a predominance of vertical root fractures (type V) (Table 2).

The analysis of fracture resistance revealed that the absence of a post reduced the fracture resistance in root filled molars compared to groups restored with glass fibre posts or cast posts, regardless of the amount of remaining coronal tooth tissue (Table 1). The lack of reinforcement of the coronal tooth tissue in this situation resulted in stresses being transferred only to the composite resin and the remaining tooth structure, inducing fractures below the loads that occurred in the groups with glass fibre posts or cast posts. Posts were able to transmit part of the loading stresses to the prepared root canals, thus distributing the load over a large surface area of the tooth structure resulting in higher fracture loads (Salameh *et al.* 2008). Thus, the findings of this study support the provision of a post in root filled mandibular molars with considerable loss of coronal tooth structure.

Glass fibre posts and cast posts resulted in similar fracture resistance regardless of the amount of remaining coronal tooth tissue (Table 1). In molar teeth, the force has a more perpendicular compressive vector, with fewer forces out of the long axis of the tooth, which is contrary to what occurs on anterior teeth where horizontal forces cause tension stress (Naumann *et al.* 2005). Consequently, it can be suggested that posts in molars teeth will be submitted to lower flexion loads and then the difference between the version post systems will not influence significantly the fracture resistance values. Other possible explanation is the high compressive resistance of the nanoparticulate resin (Z350; 3M-ESPE) associated with the glass fibre posts and formation of an unique adhesive complex amongst post, cement, composite resin and root dentine (Malferrari *et al.* 2003, Prisco *et al.* 2003, Cheung 2005) providing favourable stress distribution (Joshi *et al.* 2001, Barjau-Escribano *et al.* 2006). Moreover, the restoration of teeth with full veneer metal crowns, as was carried out in this study, or with metal-ceramic crowns reduces the post effect in the total resistance of the specimens.

Teeth with no ferrule restored with glass fibre posts or with cast posts demonstrated similar fracture resistance (Table 1); however, the fracture modes were less catastrophic for the glass fibre post group (Table 2). This information is important for clinicians to clarify that fibre posts might be indicated in mandibular molars without remaining coronal tooth tissue restored with full veneer metal crown.

Sound teeth had higher strain values in the buccal region than the other groups (Table 3). This can be explained by the absence of metallic crown and posts, which are stress concentrating factors. Teeth without a ferrule and no post had the lowest buccal strain values (Table 3) because the stresses were transferred predominantly to the resin core; thus, the cervical root dentine was not affected. This also explains the predominance of type I fractures in this group, without involvement of root structure (Table 2). In the proximal region, the strain was similar amongst all groups (Table 3). This occurred because this region is less affected in the compression load with the 25° inclination employed in this study. The fracture resistance values found in all groups tested in this study were considerably higher than the maximum physiological forces that act on posterior teeth in the oral cavity (Ahlberg *et al.* 2003, Cosme *et al.* 2005).

Conclusions

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

1. A ferrule of 2.0 mm was a determinant factor on the fracture resistance and fracture mode in root filled molar teeth restored with full metal crowns, irrespective of the post system.

2. Glass fibre posts were as effective as cast posts in the restoration of root filled molars; absence of a post decreased fracture resistance, irrespective of the amount of remaining coronal tooth tissue.

3. In teeth with remaining coronal tooth tissue, there was a predominance of catastrophic fractures irrespective of the post system, whilst teeth without remaining tooth tissue restored with cast posts suffered catastrophic fractures and teeth with glass fibre posts or no post resulted in restorable fractures.

4. Buccal strain was higher in sound teeth and lower in the teeth with no ferrule and no post. The insertion of glass fibre posts reduced buccal strain compared to the teeth with a ferrule and no post. In the proximal region, the strain was statistically similar amongst all groups of molars.

Acknowledgements

This study was supported by the Research Support Foundation of the State of Minas Gerais (FAPEMIG\Brazil). The authors are indebted to PC/ESTES/UFU for the prosthetic laboratory support to construct the cast posts and crowns.

References

Ahlberg JP, Kovero OA, Hurmerinta KA, Zepa I, Nissinen MJ, Kononen MH (2003) Maximal bite force and its association with signs and symptoms of TMD, occlusion, and body mass index in a cohort of young adults. *Cranio: The Journal of Craniomandibular Practice* **21**, 248–52.

Akkayan B (2004) An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. *The Journal of Prosthetic Dentistry* **92**, 155–62.

Akkayan B, Gülmez T (2002) Resistance to fracture of endodontically treated teeth restored with different post systems. *The Journal of Prosthetic Dentistry* **87**, 431–7.

Assif D, Gorfil C (1994) Biomechanical considerations in restoring endodontically treated teeth. *The Journal of Prosthetic Dentistry* **71**, 565–7.

Barjau-Escribano A, Sancho-Bru JL, Forner-Navarro L, Rodriguez-Cervantes PJ, Perez-Gonzalez A, Sanchez-Marin FT (2006) Influence of prefabricated post material on restored teeth: fracture strength and stress distribution. *Operative Dentistry* **31**, 47–54.

Burke FJ (1992) Tooth fracture in vivo and in vitro. *Journal of Dentistry* **20**, 131–9.

Cheung W (2005) A review of the management of endodontically treated teeth. Post, core and the final restoration. *Journal of the American Dental Association* **136**, 611–9.

Cosme DC, Baldisserotto SM, Canabarro Sde A, Shinkai RS (2005) Bruxism and voluntary maximal bite force in young dentate adults. *The International Journal of Prosthodontics* **18**, 328–32.

Ichim I, Kuzmanovic DV, Love RM (2006) A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root. *International Endodontic Journal* **39**, 443–52.

Joshi S, Mukherjee A, Kheur M, Metha A (2001) Mechanical performance of endodontically treated teeth. *Finite Elements in Analysis and Design* **37**, 587–601.

Langlade M (2002) Diagnóstico e Oclusão. In: *Diagnóstico Ortodôntico*, 2nd edn. São Paulo, SP, Brazil: Editora Santos, pp. 72–3.

Libman WJ, Nicholls JI (1995) Load fatigue of teeth restored with cast posts and cores and complete crowns. *The International Journal of Prosthodontics* **8**, 155–61.

Malferrari S, Monaco C, Scotti R (2003) Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts. *The International Journal of Prosthodontics* **16**, 39–44.

Morgano SM (1996) Restoration of pulpless teeth: application of traditional principles in present and future contexts. *The Journal of Prosthetic Dentistry* **75**, 375–80.

Morgano SM, Brackett SE (1999) Foundation restorations in fixed prosthodontics: current knowledge and future needs. *The Journal of Prosthetic Dentistry* **82**, 643–57.

Morgano SM, Rodrigues AH, Sabrosa CE (2004) Restoration of endodontically treated teeth. *Dental Clinics of North America* **48**, 397–416.

Naumann M, Blankenstein F, Kiessling S, Dietrich T (2005) Risk factors for failure of glass fiber-reinforced composite post restorations: a prospective observational clinical study. *European Journal of Oral Sciences* **113**, 519–24.

Pereira JR, de Ornelas F, Conti PC, do Valle AL (2006) Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. *The Journal of Prosthetic Dentistry* **95**, 50–4.

Pereira JR, Valle AL, Shiratori FK, Ghizoni JS, Melo MP (2009) Influence of intraradicular post and crown ferrule on the fracture strength of endodontically treated teeth. *Brazilian Dental Journal* **20**, 297–302.

Prisco D, De Santis R, Mollica F *et al.* (2003) Fiber post adhesion to resin luting cements in the restoration of endodontically-treated teeth. *Operative Dentistry* **28**, 515–21.

Rodrigues FB, Paranhos MP, Spohr AM, Oshima HM, Carlini B, Burnett LH Jr. (2010) Fracture resistance of root filled molar teeth restored with glass fibre bundles. *International Endodontic Journal* **43**, 356–62.

Salameh Z, Sorrentino R, Papacchini F *et al.* (2006) Fracture resistance and failure patterns of endodontically treated mandibular molars restored using resin composite with or without translucent glass fiber posts. *Journal of Endodontics* **32**, 752–5.

Salameh Z, Sorrentino R, Ounsi HF, Sadig W, Atiyeh F, Ferrari M (2008) The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber posts. *Journal of Endodontics* **34**, 842–6.

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

Schwartz RS, Robbins JW (2004) Post placement and restoration of endodontically treated teeth: a literature review. *Journal of Endodontics* **30**, 289–301.

Soares CJ, Pizi EC, Fonseca RB, Martins LR (2005) Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. *Brazilian Oral Research* **19**, 11–6.

Soares CJ, Martins LR, Fonseca RB, Correr-Sobrinho L, Fernandes Neto AJ (2006) Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations. *The Journal of Prosthetic Dentistry* **95**, 421–9.

Soares CJ, Santana FR, Silva NR, Preira JC, Pereira CA (2007) Influence of the endodontic treatment on mechanical properties of root dentin. *Journal of Endodontics* **33**, 603–6.

Soares PV, Santos-Filho PC, Gomide HA, Araujo CA, Martins LR, Soares CJ (2008) Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part II: strain measurement and stress distribution. *The Journal of Prosthetic Dentistry* **99**, 114–22.

Sorensen JA, Engelman MJ (1990) Ferrule design and fracture resistance of endodontically-treated teeth. *The Journal of Prosthetic Dentistry* **63**, 529–36.

Tan PL, Aquilino SA, Gratton DG *et al.* (2005) In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *The Journal of Prosthetic Dentistry* **93**, 331–6.

Tang W, Wu Y, Smales RJ (2010) Identifying and reducing risks for potential fractures in endodontically treated teeth. *Journal of Endodontics* **36**, 609–17.

Tokasvul S, Zor M, Toman M, Gungor MA, Nergiz I, Artunc C (2006) Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications. *Operative Dentistry* **31**, 89–96.

Torbjörner A, Fransson B (2004) A literature review on the prosthetic treatment of structurally compromised teeth. *The International Journal of Prosthodontics* **17**, 369–76.

Zarone F, Sorrentino R, Apicella D *et al.* (2006) Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. *Dental Materials* **22**, 1035–44.

Zhi-Yue L, Yu-Xing Z (2003) Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. *The Journal of Prosthetic Dentistry* **89**, 368–73.

