doi:10.1111/j.1365-2591.2008.01459.x

Effect of remaining dentine structure and thermal-mechanical aging on the fracture resistance of bovine roots with different post and core systems

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Abstract

Marchi GM, Mitsui FHO, Cavalcanti AN. Effect of remaining dentine structure and thermal-mechanical aging on the fracture resistance of bovine roots with different post and core systems. *International Endodontic Journal*, **41**, 969–976, 2008.

Aim To evaluate the influence of remaining dentine thickness around post and core systems and the thermo-mechanical stresses on fracture resistance of bovine roots.

Methodology This study involved 288 bovine incisor roots with standardized dimensions. Roots were randomly distributed into 24 groups (n = 12) according to root conditions [intact, semi-weakened, or weakened] and post and core systems [custom cast core, composite resin core, prefabricated metallic post, or prefabricated carbon fibre post], submitted or not to thermomechanical aging [5000 thermal cycles and 100 000 mechanical cycles at a 135-degree angle to the long axis of the root]. Specimens were submitted to a tangential compressive load (135° angle) at a crosshead speed of 0.5 mm min^{-1} until failure. Fracture resistance data were analyzed using 3-way ANOVA and Tukey test: α = 5%.

Results Roots restored with composite resin cores demonstrated no resistance to mechanical aging. No statistically significant difference was observed between aged and nonaged specimens involving all post-systems. Roots restored with custom cast cores had the highest fracture strength, followed by prefabricated metallic posts and carbon fibre posts, regardless of root conditions and thermomechanical aging. The remaining dentine thickness affected significantly roots restored with custom cast cores; weakened roots had a lower fracture resistance.

Conclusions Although custom cast cores had a higher fracture resistance when compared to the other techniques, the results were highly dependent on remaining dentine thickness. Prefabricated posts performed in a similar manner in intact, semi-weakened and weakened roots reinforced with composite resin.

Keywords: composite resin, custom cast cores, dentine, fracture resistance, prefabricated posts, root canal.

Received 23 November 2007; accepted 10 June 2008

Introduction

Generally, root filled teeth present with a greater loss of tooth structure resulting from caries, endodontic access, previous restorations, and fractures (Lui 1994, Wu *et al.* 2007). These factors might reduce the resistance of such teeth to intra-oral loads (Morgano & Milot 1993, Saupe *et al.* 1996, Ferrari *et al.* 2000b, Heydecke *et al.* 2002).

Several reports have concluded that the resistance of a root filled tooth is directly related to amount of remaining tooth structure (Sornkul & Stannard 1992, Patel & Gutteridge 1996). For this reason, the provision of a post and core must be done with care, since their use frequently requires the removal of sound tooth tissue (Sornkul & Stannard 1992, Dean *et al.* 1998). To

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avoid tooth weakening, some reports have suggested that posts should be used only when the remaining tooth structure is not sufficient to retain a restoration (Trope *et al.* 1985, Maccari *et al.* 2003, Goto *et al.* 2005).

In recent years, custom cast cores have been used less commonly and a greater variety of prefabricated posts, such as metallic posts, carbon fibre posts, and glass fibre posts, have been introduced into the market (Huysmans *et al.* 1993). Some prefabricated posts have an elastic modulus similar to that of dentine, allowing a better dissipation of intraoral loads throughout the tooth (Isidor *et al.* 1996, Dean *et al.* 1998, Ferrari *et al.* 2000a). Better aesthetics, higher biocompatibility, higher resistance against corrosion, and easier removal from the root canal are some of the potential advantages of prefabricated posts (Martinez-Insua *et al.* 1998, Ferrari *et al.* 2000a, Fernandes *et al.* 2003).

Despite advances in prefabricated systems and adhesive restorative materials, the best approach to restore severely weakened teeth remains controversial. In addition, few laboratory studies evaluating the fracture resistance of root filled teeth mimic clinical conditions (Huysmans *et al.* 1993, Patel & Gutteridge 1996, Saupe *et al.* 1996, Martinez-Insua *et al.* 1998, Marchi *et al.* 2003). In laboratory studies fatigue and thermocycling tests are important tools for the evaluation of restorative materials and techniques (Heydecke *et al.* 2001). Therefore, it is important to determine whether thermomechanical aging might affect the fracture resistance of restored roots. The purpose of this investigation was to evaluate the influence of both the remaining dentine thickness around various post and core systems (custom cast core, composite resin core, prefabricated metallic post, or prefabricated carbon fibre post), and thermomechanical aging on the fracture resistance of bovine roots. The hypotheses tested were: 1) fracture resistance might be affected by the remaining dentine thickness and by the post and core systems; and 2) thermomechanical aging might reduce the fracture resistance of the root.

Materials and methods

Restorative materials, manufacturers, classifications and characteristics are given in Table 1. Bovine mandibular incisor teeth stored in 0.1% thymol solution were used in this study. Only roots with a standardized dimension were selected. For this purpose, the average of the largest buccal-lingual end mesiodistal diameters were calculated for each root using a digital calipter (Carl Mahr, GmbH, Esslinger, Germany). All roots presenting averages lower than 6.0 mm and higher than 6.5 mm were excluded. All teeth were cleaned, pumiced, and then had their coronal portion sectioned 14.0 mm above the root apex using diamond disks (KG Sorensen, Barueri, SP, Brazil) under water cooling. A 14.0 mm root length was used because the root portion of the post and core systems was standardized at 9.0 mm and a 5.0 mm distance from the apex simulated the length of the root filling.

Roots (n = 288) with standardized dimensions were selected and randomly distributed into 24 experimental groups (n = 12) according to 'root conditions' [intact, semi-weakened, or weakened] and 'post and core systems' [custom cast core, composite resin core, prefabricated metallic post, or prefabricated carbon

Table 1 Restorative materials used in this study, classification and characteristics

Material (manufacturer)	Classification and characteristics
Palliag M (Degudent)	Silver-palladium alloy Casting with the thermal expansion technique
Radix Anker n.3 (Dentsply Maillefer)	Prefabricated metallic post Radicular portion: 9.0 mm length, 1.95 mm in diameter (including threads) Coronal portion: 3.0 mm length and 5.0 mm in diameter
Aestheti Post n.3 (Bisco)	Prefabricated carbon fibre post Radicular portion: 9.0 mm length, 1.4 mm and 2.1 mm in diameter (apical portion and medium-cervical portion, respectively)
Scotchbond Etchant (3M ESPE)	35% Phosphoric acid, silicon dioxide
Single Bond (3M ESPE)	2-steps etch and rinse adhesive system
Filtek Z250 (3M ESPE)	Universal composite resin
Rely X ARC (3M ESPE)	Dual-cure resin cement

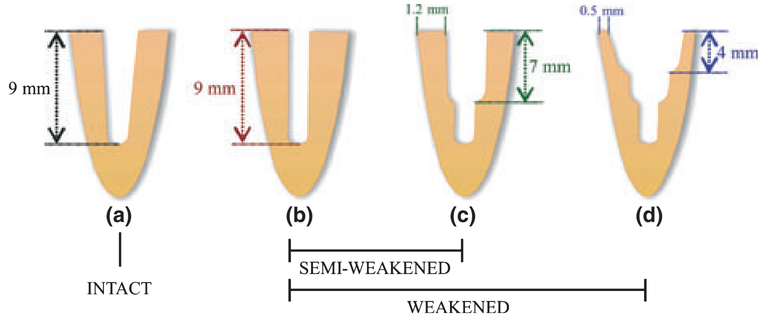

Figure 1 Schematical presentation of the post-preparations. (a) Intact root with preparation for custom cast cores and composite resin cores. (b and c) Preparation of semi-weakened roots. (b–d) Preparation of weakened roots.

fibre post], submitted or not to 'thermomechanical aging'.

Intraradicular preparation of intact roots

For custom cast cores and composite resin cores, post-hole preparations were completed using a conical diamond bur (number 3070, KG Sorensen, Barueri, Sao Paulo, Brazil – 10.0 mm length and 1.4 mm diameter) in a low-speed handpiece under water cooling. The root canal was prepared to a depth of 9.0 mm (Fig. 1a). Burs were replaced after every five preparations.

For the prefabricated metallic post (Radix Anker, Dentsply Maillefer, Ballaigues, Switzerland) and the prefabricated carbon fibre post (Aestheti Post, Bisco, Schaumburg, IL, USA), roots were prepared according to the manufacturer's instructions using the drills and devices of each system (dimensions of burs: Radix: 9.0 mm length and 1.65 mm diameter; Aestheti Post: 9.0 mm length and 1.4 and 2.1 mm diameters). The standardized 9.0 mm depth was adapted during canal preparation. The prefabricated metallic posts were threaded into the root canal with a specific screwdriver. When slight resistance during placement was noted, the post was rotated half a turn counterclockwise to avoid tension within the root.

Intraradicular preparation of semi-weakened roots

A ball-shaped diamond bur (number 1016 HL, KG Sorensen, Barueri, Sao Paulo, Brazil – 1.8 mm diameter) was used to create a standardized coronal access preparation to a depth of 9.0 mm (Fig. 1b). Then, another ball-shaped diamond bur (number 3017 HL, KG Sorensen, Barueri, Sao Paulo, Brazil – 2.5 mm diameter) was used to enlarge the root canal to a depth of 7.0 mm (Fig. 1c). The preparations left the cervical third of the root with a 1.2 mm remaining dentine thickness.

Intraradicular preparation of weakened roots

Initially, a ball-shaped diamond bur (number 1016 HL, KG Sorensen, Barueri, Sao Paulo, Brazil) was used to create a standardized intraradicular access preparation to a depth of 9.0 mm (Fig. 1b). Then, another ball-shaped diamond bur (number 3017 HL, KG Sorensen, Barueri, Sao Paulo, Brazil) was used to prepare the middle third of the root canal to a depth of 7.0 mm (Fig. 1c). Finally, a third ball-shaped diamond bur (number 3018 HL, KG Sorensen, Barueri, Sao Paulo, Brazil – 2.9 mm diameter) was used to prepare the cervical third of the canal to a depth of 4.0 mm (Fig. 1d). The preparations left the cervical third of the root with a 0.5 mm remaining dentine thickness.

Restorative procedures

Custom cast cores

Root canal walls were lubricated and replicated with self-cure acrylic resin (Duralay, Reliance Dental, Worth, IL, USA). The coronal portion of the acrylic pattern was 3.0 mm high and 5.0 mm in diameter (±0.2 mm) (same shape and dimensions protruding from face of the coronal portion of the prefabricated metallic post). Casting was carried out using a silver-palladium alloy (Palliag M, Degudent, Hanau, Germany).

Custom cast cores were attached with dual-cure resin cement (RelyX ARC, 3M ESPE, St. Paul, MN, USA) prepared according to manufacturer's instructions. First, root canal walls were etched with 35% phosphoric acid for 15 s, followed by thorough rinsing and drying with paper points. Two thin consecutive coats of Single Bond adhesive system (3M ESPE, St. Paul, MN, USA) were applied, gently air-dried for 5 s, excess carefully removed with paper points, and then light-cured for 10 s. The resin cement was applied to the custom cast cores which were then seated, held in the proper position, and light-cured for 40 s. Cement excess was removed before light-curing.

Composite resin cores

The root canals were etched with 35% phosphoric acid and the Single Bond adhesive system was applied as described above. The root canal was then filled with four increments of composite resin (2.0 mm/each) of composite resin (Filtek Z250, 3M ESPE, St. Paul, MN, USA) which were light-cured separately. The first two increments were light-cured for 80 s due to a deeper extension of the root preparation. The other increments were light-cured for 40 s. The coronal portions of the composite resin cores were 3.0 mm high and 5.0 mm in diameter (±0.2 mm).

Prefabricated metallic posts and carbon fibre posts

In the intact roots, prefabricated posts were cemented with the dual-cure resin cement using the same protocol previously described. A layer of adhesive system was applied on the prefabricated fibre post, following the recommendation of its manufacturer. The coronal portion of the carbon fibre post was built-up with composite resin [3.0 mm high and 5.0 mm (±0.2 mm) in diameter].

For the semi-weakened and weakened roots, the adhesive system was applied, the post was lubricated with vaseline and positioned inside the root canal, and composite resin was used to fill the root canal defects around the post. The first layer of composite resin (2-mm thick) was light-cured for 80 s and the others for 40 s. Posts were then cemented with the same protocol described before. Composite resin was also used to build the coronal portion of the carbon fibre post [3.0 mm high and 5.0 mm (±0.2 mm) in diameter].

A halogen light-curing unit (Optilux 501, Sybron Kerr, Danbury, CT, USA) was used during all restorative procedures. The constantly-monitored output of the light-curing unit was greater than 660 mW cm^{-2}. After cementation procedures, specimens were stored in a 0.9% saline solution for 24 h.

Thermomechanical aging

Before thermomechanical aging, roots were embedded in polystyrene resin cylinders (Cromex, Piracicaba, Sao Paulo, Brazil), 11.0 mm from the root apex, simulating the 3.0-mm biological width.

Thermal variations were induced in a thermal cycling machine (MCT2-AMM2, São Paulo, SP, Brazil). Teeth were submitted to 5000 thermal cycles in water at temperatures ranging from 5°C (±2) to 55°C (±2) with a 1 min dwell time at each temperature and a transfer time of 5 s.

During mechanical cycling, a metallic coping (0.5 mm thick) with a small concavity on the palatal side was passively placed, not luted, over the coronal portion of the prefabricated posts and composite resin cores. The metallic coping did not touch the root; therefore, no ferrule effect was simulated. The coping was used to support the compression force of the loading tip during mechanical cycling and to guarantee that the load would be placed at the same location in all groups. The concavity was created will a ball-shaped diamond bur (number 3017 HL, KG Sorensen, Barueri, Sao Paulo, Brazil). On the custom cast cores, a small concavity with the same dimension was prepared directly on their coronal portion using the same size/shape bur. Specimens were positioned in a mechanical loading machine (ER-FOP 10, Erios Internacional, São Paulo, SP, Brazil) at a 45° angle to the horizontal plane. The loading device delivered an intermittent axial force at a 135° angle to the long axis of the root. Roots were submitted to 100 000 cycles (80 N and 3.5 Hz) (Marchi *et al.* 2003, Mitsui *et al.* 2004).

Fracture resistance test

Specimens were placed into a cylindrical concavity located in the centre of a sloping plane (Fig. 2). This plane was positioned at a 45° angle to the base of a stainless steel metal device. A compression load was applied to the metallic coping, which was passively placed over roots restored with prefabricated metallic posts, carbon fibre posts and composite resin cores. This coping did not simulate a coronal restoration and its use was intended to position the compression load at the same location. On custom cast cores, the compression load was placed directly onto the concavity prepared previous to the mechanical cycling. Fracture testing was performed in a universal testing machine (EMIC DL 500, São José dos Pinhais, SC, Brazil) at a 135° angle to the long axis of the roots and a crosshead speed of 0.5 mm min^{-1} until failure.

Fracture resistance data (kgf) were analysed statistically using the three-way ANOVA (root condition x post and core x thermomechanical aging). All possible

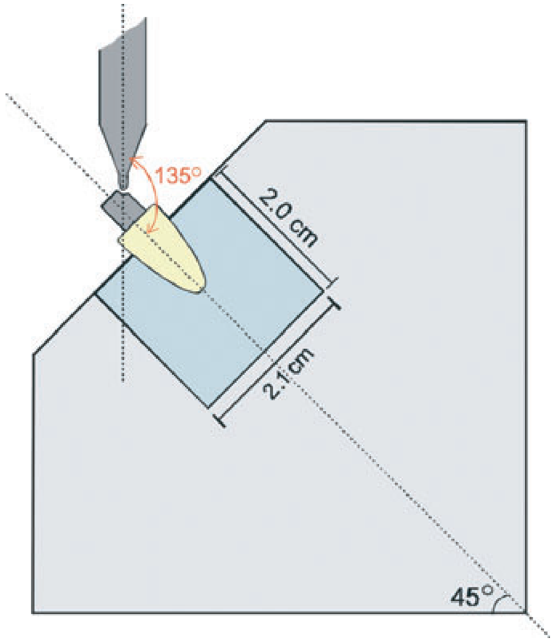

Figure 2 Schematical presentation of the fracture testing device.

interactions were included in the model. Multiple pairwise comparisons were made using the Tukey post-hoc test. The software SAS 8.0 (SAS Institute, Cary, NC, USA) was used for the statistical analysis at a significance level of 5%.

Results

Table 2 shows mean values for fracture resistance and standard deviations. Roots restored with composite resin cores demonstrated no resistance to the thermo-mechanical aging. For that reason, they were not included in the statistical analysis. Groups submitted or not to mechanical presented similar fracture resistance ($P > 0.05$).

A significant interaction was observed between condition of root and intra-radicular retention ($P = 0.03$). Roots restored with custom cast cores had greater fracture resistance values when compared to those restored with prefabricated metallic posts and carbon fibre posts, regardless of root condition and thermomechanical aging ($P = 0.0001$). Lower mean values were observed for roots restored with carbon fibre posts when compared with prefabricated metallic posts ($P = 0.0001$). The remaining dentine structure significantly affected roots restored with custom cast cores. Lower fracture resistance was observed for weakened roots ($P = 0.0001$).

Discussion

Root canal treatment might result in larger root canals and thinner surrounding dentine walls (Lui 1994, Wu *et al.* 2007). In most cases, the loss of tooth tissue is limited to the cervical third of the root, while the apical third remains relatively intact with significant dentine structure and adequate periodontal support (Lui 1994, Marchi *et al.* 2003). The minimum thickness of dentine required around a post is uncertain, and values from 1.0 to 1.75 mm are often suggested (Lloyd & Palik 1993). In the present study, standardized canal preparations were performed to 'weaken' roots (leaving the cervical third with 0.5 mm remaining dentine thickness) and to 'semi-weaken' the roots (leaving the cervical third with 1.2 mm remaining dentine thickness).

Table 2 Mean (standard deviation) of the fracture resistance (kgf)

		Root condition		
Aging condition	Post and core system	Intact	Semi-weakened	Weakened
Groups not aged	Custom cast core	76.57 (7.47) Aa [12]	79.67 (14.80) Aa [12]	63.17 (12.78) Ab [12]
	Metallic post	63.13 (10.97) Ba [12]	59.30 (9.14) Ba [12]	54.08 (11.62) Ba [12]
	Carbon fibre post	38.30 (5.94) Ca [12]	38.97 (7.62) Ca [12]	39.87 (7.58) Ca [12]
	Composite resin core	14.32 (8.84) [12]	17.98 (8.77) [12]	24.83 (7.73) [12]
Thermo mechanical aging	Custom cast core	76.90 (8.30) Aa [12]	75.85 (8.37) Aa [10]	65.15 (7.67) Ab [12]
	Metallic post	55.60 (7.20) Ba [11]	51.27 (9.40) Ba [12]	52.20 (8.70) Ba [11]
	Carbon fibre post	47.92 (10.76) Ca [12]	40.47 (10.47) Ca [12]	34.00 (6.51) Ca [9]
	Composite resin core	[0]	[0]	[0]

Means followed by the same letters are not statistically different (3-Way ANOVA/Tukey test. α = 5%). Capital letters compare post and core systems under each root condition. Low case letters compare root conditions within each post and core system. Composite resin cores were not included in the statistical analysis. Square brackets [ ] represent the number of specimens tested per group. Coefficient of variation: 16.88%.

It has been stated that a ferrule effect can significantly modify the fracture strength of the roots (Isidor *et al.* 1999). A ferrule is defined as a vertical band of tooth structure at the gingival aspect of a crown preparation that primarily provides resistance form and enhances longevity of restorations (Isidor *et al.* 1999, Stankiewicz & Wilson 2002). However, the ferrule should not be provided at the expense of remaining tooth/root structure (Stankiewicz & Wilson 2002). Since the actual influence of the post and core systems on fracture resistance of roots was the primary aim of the present investigation, no ferrule effect was simulated.

The various remaining dentine thickness around post and core systems were submitted to thermomechanical stresses simulating clinical conditions. The mechanical load was applied at a 135° angle to simulate a Class I occlusal relationship between maxilary and mandibular incisors (Goto *et al.* 2005). Thermomechanical stresses did not affect fracture resistance, regardless of the root condition or the post and core system. There is a significant variation among aging methods in the literature (Huysmans *et al.* 1993, Drummond *et al.* 1999). Therefore, it is not reasonable to compare the results of the present study to those of previous investigations using different aging protocols. In addition, it would be unwise to state that the aging simulation had no effect on the specimens tested since the composite resin cores showed no resistance to mechanical cycling.

In the present study, groups restored with custom cast cores had a significantly higher fracture resistance. This result is in accordance with findings reported in previous studies (Fraga *et al.* 1998, Martinez-Insua *et al.* 1998), and may be explained by the fact that the custom cast cores are better fitted to the dentine wall. Custom cast cores consist of homogeneous structures which reproduce the inner contour of the root canal (Saupe *et al.* 1996).

While the custom cast cores had higher fracture resistance, prefabricated posts had better clinical characteristics, such as the easier and time-saving placement techniques, requiring only one clinical appointment (Morgano & Milot 1993). In the present study, prefabricated metallic posts had higher fracture resistance when compared to carbon fibre posts. This result might be related to the high rigidity of prefabricated metallic posts (Lambjerg-Hansen & Asmussen 1997); it might also be explained by the type of intraradicular retention of the metallic post. The active placement of Radix-Anker might provide higher mechanical retention (Purton & Love 1996, Fernandes *et al.* 2003).

It has been hypothesised that a less stiff post provides a more uniform stress distribution. Some investigations found that the resistance to fracture of roots restored with carbon fibre posts to be equivalent or higher than that of roots with metallic prefabricated posts (Isidor *et al.* 1996, Hu *et al.* 2003). Nevertheless, the contrary result was observed in the present investigation. The lower fracture resistance of prefabricated fibre posts is in accordance with the reports of a previous study, which compared such posts to prefabricated metallic posts and custom cast cores (Sidoli *et al.* 1997). During the microanalysis of post-surfaces, these authors noted progressive failures in carbon fibre surfaces, but only a minor bending was observed in metallic post-surfaces. In another study, authors have stated that stiffness is highly dependent on the post-diameter; and a carbon fibre post of greater diameter can be stiffer than a metallic post of less diameter (Asmussen *et al.* 1999). Therefore, it is unclear whether fracture resistance can be related to the stiffness of the post or not. The low fracture resistance observed in roots restored with carbon fibre posts might be related to the absence of a proper mechanical retention, since these posts are only adhesively retained in the root canal, and thus depend on a good bond between the resin-based materials and the root canal walls (Purton & Love 1996).

The remaining dentine thickness was a determinant factor on the fracture resistance of roots restored with custom cast cores; the intact roots had significantly higher values compared to the weakened ones. This finding indicates that the fracture resistance of roots restored with custom cast cores is directly related to the remaining tooth structure (Sornkul & Stannard 1992, Lloyd & Palik 1993, Patel & Gutteridge 1996). Considering the great possibility of catastrophic failures, custom cast cores do not seem to be the best option to restore roots with severe loss of tooth structure. On the other hand, the prefabricated posts revealed the same results for weakened and semi-weakened roots. In contrast to the metal structure of custom cast cores, the composite resin used around the prefabricated posts might have reinforced the weakened and semi-weakened roots (Lui 1994), increasing their fracture resistance.

Composite resin has been used to fill the root canal of endodontically treated teeth (Lui 1994, Saupe *et al.* 1996, Marchi *et al.* 2003). It was previously stated that teeth with a significant amount of sound structure might have a successful prognostic factor when the root canal is bonded and filled with composite resin (Sornkul & Stannard 1992). Conversely, in the present study, the fracture resistance of composite resin cores could not be evaluated because aged specimens failed during mechanical cycling. Failures occurred within the composite resin structure or in the interface between the composite resin and the dentine wall. It was suggested that failures related to restorative materials instead of tooth structure might be considered beneficial, since the tooth will be preserved and the restoration can be replaced (Fraga *et al.* 1998). However, it is questionable whether these failures are advantageous; the fracture resistance of the composite resin cores was so low that they could not resist the 100 000 mechanical load cycles. The complete absence of a ferrule might be related to this weak resistance against mechanical loads (Isidor *et al.* 1999). The first hypothesis tested in the present study was accepted since the custom cast cores were significantly affected by the remaining dentine structure. However, the second hypothesis was not accepted because thermomechanical aging did not affect the fracture resistance of the roots.

Conclusion

Thermomechanical aging did not affect the fracture resistance of the post and core build-up systems, except for composite resin cores. Roots restored with custom cast cores had higher fracture resistance, followed by prefabricated metallic posts and carbon fibre posts. Finally, the remaining dentine thickness was an important factor for the fracture resistance, regardless of the intraradicular retention system used; this effect was more prominent for custom cast post and cores.

Acknowledgements

This work was sponsored by FAPESP, contract grant number 01/02974-5.

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