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Influence of elastic modulus of intraradicular posts on the fracture load of roots restored with full crowns

Influência do modulo de elasticidade de retentores intrarradiculares na carga para fratura de raízes restauradas com coroas totais

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Resumo

Objetivo: Este trabalho avaliou a carga para fratura e deslocamento de raízes restauradas com pinos de diferentes módulos de elasticidade. **Material e método:** Trinta e seis réplicas de microfibras de vidro embutidas em resina epóxi foram fabricadas a partir de uma raiz de um pré-molar tratado endodonticamente preparado em 12 mm de comprimento com brocas customizadas, deixando 4 mm apicais sem preparo. As raízes foram randomicamente restauradas com (n = 12): FP-LM (pino de fibra com um baixo módulo de elasticidade – 50 GPa), FP-HM (pino de fibra com um alto módulo de elasticidade – 67 GPa) e MP (pinos metálicos – 208 GPa), usando adesivo autopolimerizável e cimento resinoso dual. Núcleos foram confeccionados com resina composta e coroas metálicas foram cimentadas em todas as raízes com cimento resinoso autoadesivo com modo de polimerização químico. Os espécimes foram submetidos ao teste de fratura em 45° (inclinação de 45° / 0,5 mm/min) e o deslocamento foi registrado aos 100 N. **Resultado:** Anova 1 fator mostrou que o módulo de elasticidade dos retentores não afetou as médias de fratura (p = 0,203) (FP-LM: 237,4 ± 65,11 N; FP-HM: 236,7 ± 92,85 N; MP: 295,8 ± 108,7 N) mas foi estatisticamente significante para o deslocamento (p < 0,00): o teste de Tukey mostrou que a média de deslocamento do grupo FP-LM (0,81 ± 0,15 mm) foi significativamente maior do que o grupo FP-HM (0,46 ± 0,26 mm; p = 0,00) e MP (0,62 ± 0,07 mm; p = 0,47). **Conclusão:** Pinos com diferentes módulos de elasticidade mostram resistência similar, porém um menor deslocamento é obtido quando pinos de fibra com alto módulo de elasticidade (FP-HM/MP) são usados.

Descritores: Força compressive; retentores intrarradiculares; materiais dentários; prótese dentária.

Abstract

Objective: This study aimed to evaluate the fracture load and displacement of roots restored with posts of different elastic modulus. **Material and method:** Thirty-six replicas of epoxy resin mixed with glass microfibers were made from an endodontically-treated human premolar root prepared to a length of 12 mm with a custom drill, leaving the apical 4 mm unprepared. Replicas were randomly restored with (n = 12): FP-LM (fiber post with low elastic modulus– 50 GPa), FP-HM (fiber post with high elastic modulus – 67 GPa) and MP (metallic post – 208 GPa), using self-curing adhesive and dual resin cement. Cores were built up with composite resin and metallic crowns were cemented in all the roots with self-adhesive resin cement with self-curing mode. Specimens were subjected to a fracture load test (45° inclination/0.5 mm/min) and displacement was registered at 100 N. **Result:** One-way ANOVA showed that elastic modulus of the post did not affect the fracture load means (p = 0.203) (FP-LM: 237.4 ± 65.11 N; FP-HM: 236.7 ± 92.85 N; MP: 295.8 ± 108.7 N) but was statistically significant for the displacement (p < 0.00): Tukey's test showed that FP-LM displacement mean (0.81 ± 0.15 mm) was significantly higher than those for FP-HM (0.46 ± 0.26 mm; p = 0.00) and MP (0.62 ± 0.07 mm; p = 0.04). **Conclusion:** Posts with different elastic modulus exhibit similar fracture loads, but a lower displacement is achieved when fiber posts with a high elastic modulus and metallic posts are used.

Descriptors: Compressive strength; intraradicular posts; dental materials; dental prosthesis.

INTRODUCTION

The proper esthetic and functional reconstruction of endodontically treated teeth is a crucial factor for long-term success of the rehabilitation[1]. Endodontically treated teeth commonly present substantial destruction of tooth structure resulting from caries, dental fracture and cavity preparation for endodontic therapy, making the retention of restorative materials difficult[2]. When there is loss of more than half of the coronal structure, intraradicular posts are recommended to retain the restorative materials used to reconstruct the tooth crown and to distribute stress along the root[3,4]. However, intraradicular posts do not reinforce the remaining dental structure[3].

To select the most suitable post it is necessary to consider many factors like the position of the tooth, degree of dental destruction and type of restoration to be placed[5]. Different post systems options with diverse elastic modulus are available for restoration of endodontically treated teeth. Cast post and cores and, more recently, prefabricated metallic posts have been used. According to finite element analyses, such posts with an elastic modulus superior to that of dentin concentrate high stress on the radicular dentin, which may increase the risk of root fracture[6]. Carbon and glass fiber posts were developed as an alternative to metallic posts to improve esthetics and adhesion to the dental structure. Due to mechanical properties similar to dentin, fiber posts transmit less stress to the remaining dentin and decrease the risk of root fracture since it is likely that the post/core will fail before the root fractures[6].

Although the rigidity of the intracanal anchorage should be taken into consideration since it may influence the mechanical behavior of the restored endodontically treated teeth[6], most studies which evaluated the fracture strength of teeth restored with different post materials used diverse post systems with varied shapes and diameters[1,7,8], making it difficult to isolate the variable "post rigidity". For this reason, this study focused on the evaluation of posts with the same format.

Thus, the purpose of this *in vitro* study was to evaluate the effect of different elastic modulus of intraradicular posts on the fracture load and displacement of roots restored with full crowns. The hypotheses tested were that different elastic modulus would generate similar fracture load and would not affect displacement of the restored teeth.

MATERIAL AND METHOD

A single-root human premolar extracted for orthodontic reason with no caries, no previous endodontic treatment, restorations or cracks, and formed apex, was cleaned with periodontal curettes and disinfected with sodium hypochlorite 5% for 10 min. The crown was sectioned at the cement-enamel junction under cooling. The root (length: 16 mm) was endodontically treated with the step-back technique with stainless steel reamers (FGK, La Chaux-de-Fonds, Neuchâtel, Switzerland) until #50 and Gates-Glidden drills #1, #2 and #3 (Dentsply-Maillefer, Ballaigues, Vaud, Switzerland), using 2 ml of 5% sodium hypochlorite and 1 ml of 17% EDTA trisodium gel after the use of each instrument. The canal was then prepared with a #3 drill (Hi-Rem Prosthetic Post, Overfibers, Mordano, BO, Italy) to a 12 mm length, leaving the apical 4 mm unprepared.

The tooth was prepared for a full crown with a 1 mm-depth chamfer located 2 mm from the cervical margin to provide a ferrule effect. The root was molded with addition silicone (Elite HD+, Zhermack, Badia Polesine, RO, Italy) and 36 replicas of epoxy resin (Schaller 285, Model Center Schaller, Firenze, FI, Italy) mixed with glass microfibers (R & G, Waldenbuch, Baden-Württemberg, Germany) (30% by weight), with the same external and intracanal morphology to the original root were obtained.

Replicas were randomly divided into three groups (n=12) according to the post: FP-LM (fiber post with low elastic modulus), FP-HM (fiber post with high elastic modulus) and MP (metallic post). For FP-HM, conical-cylindrical posts (Hi-Rem Prosthetic Post, Overfibers, Mordano, BO, Italy) with elastic modulus 67 GPa were used. For FP-LM, fiber posts were exclusively fabricated for this investigation by the same manufacturer with the same shape as a Hi-Rem Prosthetic Post but with a lower elastic modulus (50 GPa). For MP, Co-Cr alloy (Heraenium PW, Heraeus Kulzer, Hanau, Hessen, Germany) posts (elastic modulus = 208 GPa) with the same shape as the aforementioned posts were cast. All posts had 0.9 mm diameter at the apical third, conicity of 0.08% and maximum diameter of 1.8 mm at the cervical third. Young's modulus of the post materials was measured with three-point bending tests in accordance with ISO 3312[9] and ISO 14125[10].

The root canals were conditioned with 36% phosphoric acid (Detrey Conditioner 36, Dentsply, York, PA, USA) for 15 s and washed for 15 s. Excess water was removed with absorbent paper points. Adhesive (XP Bond, Dentsply, York, PA, USA) and activator (Self Cure Activator, Dentsply, York, PA, USA) were mixed in a 1:1 ratio for 2 s, applied into the canal using an applicator tip (Micro Brush Etch/Seal Blue 100, Dentsply, York, PA, USA) and left undisturbed for 20 s. Solvent was removed by air from a dental syringe for 5 s. Posts were cleaned with 70% ethanol, the adhesive mixture was applied onto the surface and left undisturbed for 5 s, and then air dried for 5 s. All posts had a length of 15.5 mm (3.5 mm coronal portion and 12 mm intracanal portion). Resin cement (Core X Flow, Dentsply, York, PA, USA) was inserted into the canal with the mixing tip, posts were positioned inside the canal, excess cement was removed and photoactivation was performed for 20 s. After cementation, all roots were embedded in resin epoxy cylinders (Technovit 4071, Heraeus Kulzer) up to 1.5 mm from the cervical margin.

Identical silver-palladium (Valcambi, Balerna, Ticino, Switzerland) crown frameworks were cast using the lost-wax technique. Cores were built up as follows: 1 – the coronal part of the root and post were etched and the adhesive mixture was applied in the same manner as for post cementation; 2 – each framework was internally lubricated with Vaseline; 3 – Core X Flow was inserted inside the frameworks and on the post, frameworks were positioned over the coronal portion of the roots and excess was removed with a microbrush; 4 – after 6 min, the frameworks were removed and the cores were photoactivated for 20 s; 5 – the frameworks were tried onto their respective cores, and when binding was encountered, the axial walls of the cores were adjusted so that every crown could reach the maximum seating. After core reconstruction, cores and frameworks were cleaned with 70% ethanol and the internal surface of frameworks was abraded with 50 µm aluminum oxide particles. Resin cement (Smartcem 2, Dentsply, York, PA, USA) was inserted inside the crowns with the mixing tip, crowns were settled in position over the casts and the cement excess was removed. Specimens were left undisturbed for 30 min.

Specimens were cleaned in a 37 °C ultrasonic bath for 15 min and then stored in 37°C water for 24 h. The fracture load test was executed in a universal testing machine (Instron 4465, Instron, Norwood, MA, USA) 24 h after cementation. Each specimen was positioned on a device at an angle of 45° in relation to the tooth long axis and a constant load at a crosshead speed of 0.5 mm/min was applied until failure (1000 N load cell). Specimens were examined under a stereomicroscope (Leica M-10, Wild Heerbrugg, Heerbrugg, Sankt Gallen, Switzerland) and failures were classified as shown in Figure 1A-D.

Graphics of the relation between the force applied (N) and the displacement (mm) until failure were registered for each specimen during the fracture load test. Displacement at 100 N load was recorded and compared among the groups.

RESULT

Normal distribution and homoscedasticity were verified with the Shapiro–Wilk and Levene's test. Fracture load values were analyzed by one-way ANOVA. Displacement data were analyzed by one-way ANOVA and Tukey's test. The significance level was 5%. Table 1 summarizes the fracture load means and standard deviations: post type did not affect the fracture load ($p = 0.203$). Failures were predominantly caused by detachment between cervical dentin and core with post pull-out (Table 1).

Displacement means and standard deviations at 100 N are presented in Table 1. The type of intraradicular post was statistically significant ($p = 0.00$): Tukey's test showed that FP-LM displacement was significantly higher than that for FP-HM ($p = 0.00$) and MP ($p = 0.04$). Statistical power was calculated using a statistical software (Power of 0.93 for fracture load and 0.99 for displacement).

DISCUSSION

Since the elastic modulus of a post may influence the clinical performance of a restored tooth, the fracture load and displacement of roots restored using intraradicular posts with different elastic modulus were evaluated.

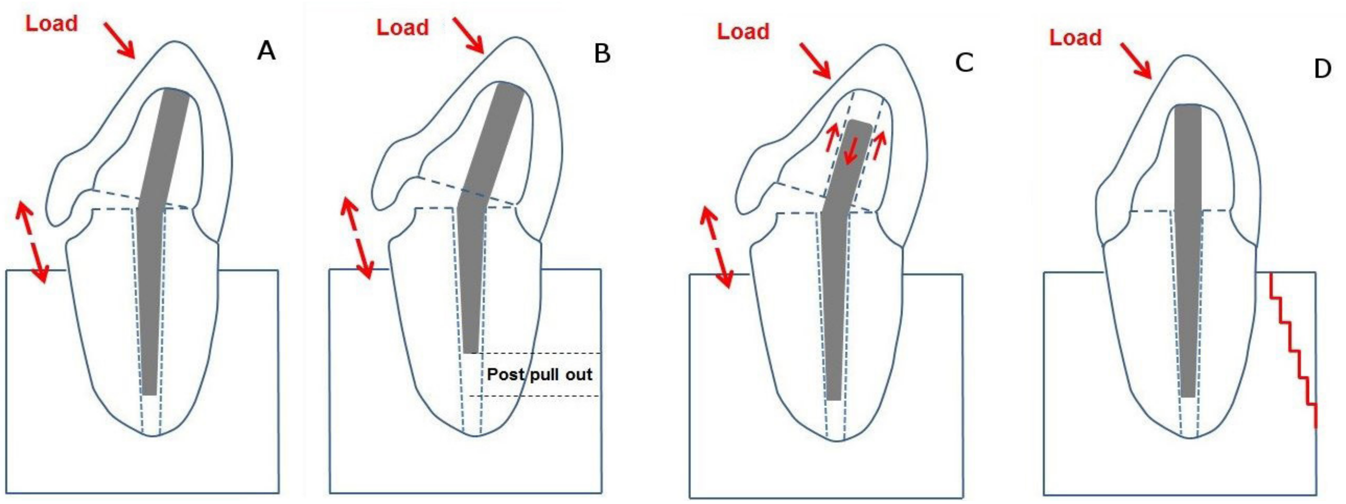

Figure 1. Schematic representation of the modes of failure. (A) DC: detachment between cervical root third and core; (B) DC/P: detachment between cervical root third and core with post pull-out; (C) CP: detachment between core and post; (D) F: fracture of the resin cylinder.

Table 1. Fracture load (N) means and standard deviations (SD), failure modes after the fracture load test and displacement

Group	Fracture load	Failure mode**				Displacement (mm)*
	Mean (SD)	DC	DC/P	CP	F	Mean (SD)
FP-LM	237.4 (65.11)^{A}	3	8	1	-	0.81 (0.15)^{A}
FP-HM	236.7 (92.85)^{A}	4	4	4	-	0.46 (0.26)^{B}
MP	295.8 (108.7)^{A}	5	5	-	2	0.62 (0.07)^{B}
		12 (33.33%)	17 (47.24%)	5 (13.88%)	2 (5.55%)	

*Different uppercase letters indicate a statistically significant difference ($p < 0.05$). ** DC: Detachment crown; DC/P: Detachment crown/core/post assembly; CP: Detachment crown/core assembly; F: fracture of acrylic cylinder.

In this study we attempted to eliminate some of the variables which are inevitably present in *in vitro* studies evaluating the mechanical behavior of pulpless teeth. Human teeth, even within a certain range of acceptability, present inherent variations in size and morphology and may behave differently under mechanical loads due to chemical-physical differences, amorphous phase content and elastic modulus[11]. The use of identical resin replicas constructed from only one dental element with the same external and intracanal morphology were used to standardize the roots dimensions and ensure specimens uniformity. In addition, although some studies have evaluated the influence of different intraradicular posts on the mechanical behavior of pulpless teeth, most of the post systems used did not present exactly the same form and diameter among the groups as the post characteristics were previously defined by the manufacturers[7,8], so the whole restorative technique was evaluated and not only the elastic modulus of the intraradicular post. In the current study all posts had the same shape and diameter so that the elastic modulus of the posts was the only factor evaluated.

No difference was observed between the three types of post in the fracture load test, thus the first research hypothesis was accepted. The absence of difference may be related to the ferrule effect provided for all specimens. The presence of a cervical ferrule positively affects the stress distribution pattern by reducing stress concentration on the root and risk of tooth fracture. Finite element analysis shows that the ferrule effect attenuates stress intensity on the root when either metal or fiber posts are used[12-15]. Previous studies also did not find a difference in fracture resistance between teeth restored with crowns and cast and post cores or fiber posts when a ferrule was present[13,16,17]. As long as there is ferrule presence, the effect of the stiffness of the post system is secondary for the mechanical behavior of endodontically treated teeth[16], thus the difference between the elastic modulus of the post materials was minimized by the ferrule. Figure 2 shows a representation of the bending moments on the post. Fulcrum 1 is formed on the cervical level by 45° load and cervical surface of the root. Fulcrum 2 is formed at the ferrule level by 45° load and ferrule surface. As the distance between the loading point and the fulcrum 1 is higher than the distance between the loading point and fulcrum 2, the moment 1 (M1) is higher than the moment 2 (M2). So, in a tooth without ferrule the bending effect is higher on the crown/core/post assembly (Fulcrum 1) in comparison to a tooth with ferrule (Fulcrum 2). The ferrule effect protects the restorative assembly since the distance between the loading point and the support point of the crown/core/post assembly is reduced, minimizing the consequences of the bending moment at 45°. Since the bending moment is lower at the crown/core/post assembly in a tooth with a ferrule, the influence of the elastic modulus of the posts may be reduced. It is possible that in the absence of the ferrule effect MP could have had a statistically superior load since it presented a consistently higher fracture load (by approximately 25%) than the other groups, possibly because of its superior rigidity.

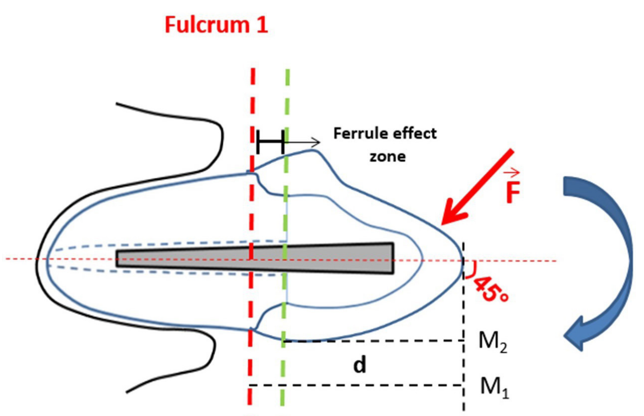

Figure 2. Schematic representation of the bending moments acting on the post. Red line: fulcrum 1. Green line: fulcrum 2. M: bending moment, which is measured by multiplying the applied force (F) with the distance between the load application point and the fulcrum line (d). M1: moment 1. M2: moment 2.

In the current study the predominant failure modes were cervical root third/core detachment and cervical root third/core detachment associated with decementation of the post. Loading at 45° to the palatal surface results in compressive stresses on the buccal surface and tensile stresses on the palatal surface[18]. These stresses are minimum in the center and maximum in the outer portions of the restorative assembly, so the higher tensile stress is concentrated in the outer cervical lingual portion[18,19] leading to adhesive failures between crown/core/post and cervical root third (DC failure mode). Besides tension and compression, loading at 45° also produces shear stress. It is maximum in the central area of the dental element, where the post is placed[18,19] and acts on the entire coronal interface (resin core/post) and intraradicular interface (post/cement/dentin), resulting in failure modes DC/P (adhesive failure between post and intraradicular resin) and CP (adhesive failure between core and post). Except for two cylinder fractures, all failures could be considered repairable, i.e. with possibility of re-intervention and preservation of the tooth[4]. These findings may also be associated with the presence of a ferrule, which has a protective effect since it improves the mechanical behavior of pulpless teeth by reducing cervical stress level on the restored root[14,16]. Other studies have shown that the ferrule effect provided by remaining dentin is associated with restorable failure modes[20-22].

Displacement measurement associated with mechanical tests and failure mode analysis contributes to a better understanding of the behavior of the restorative complex during loading[13,16]. Teeth are submitted to stress concentration and strain under load application. If the strain values exceed the resistance capacity, the restoration becomes structurally compromised, resulting in gaps at the adhesive interface, microleakage or cracks[23]. In the present study, fiber posts with a low modulus of elasticity showed higher displacement than the other groups. When a system with components presenting different elastic modulus is loaded, the most rigid material resists greater loads without distortion[24]. So, the observed findings may be explained by the fact that a less rigid material, i.e. FP-LM, is less resistant to deformation and consequently shows higher displacement.

The present study has limitations. Firstly, the elastic modulus of the replicas was approximately 5 GPa, which is lower than that of human dentin and thus does not exactly reproduce the clinical situation. Secondly, element finite analysis was not performed to determine the effect of the posts' elastic modulus on stress distribution. Finally, no aging was performed. Monotonic tests do not perfectly simulate the dynamic conditions found in the oral environment; mechanical cycling could approximate the experiment to the clinical reality by inducing degradation of the restorative materials and adhesive interfaces due to mechanical and/or thermal solicitation. Although not statistically different, MP showed a higher fracture load than the other groups. If mechanical cycling had been performed, it is possible that a significant difference could be noted since repeated loads on the structure may propagate microscopic defects located in stress concentration areas, causing fracture due to fatigue at lower loads than under monotonic testing[25]. Further research is necessary to investigate this aspect.

CONCLUSION

In the experimental conditions of this study it can be concluded that all the evaluated posts with different elastic modulus seem adequate for restoration of endodontically treated teeth regarding fracture loads. However, fiber posts with a high elastic modulus and metallic posts present lower displacement of the tooth-restoration assembly.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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