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Stress Generated by Customized Glass Fiber Posts and Other Types by Photoelastic Analysis

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Endodontic posts are necessary to provide adequate retention and support when no sufficient remaining structure is available to retain the core. There are different materials and techniques to construct post-and-core, but there is no consensus about which one promotes better stress distribution on the remaining tooth structure. This study aimed to quantify and evaluate the distribution of stress in the root produced by customized glass fiber posts compared to different endodontic posts. Twenty-five simulated roots from photoelastic resin were made and divided into 5 groups: CPC, cast post-and-core; SP, screw post; CF, carbon fiber post; GF, glass fiber post; and CGF, customized glass fiber post. After cementing CPC and SP posts with zinc phosphate cement, and CF, GF and CGF posts with resin cement, resin cores were made for groups 2–5. Specimens were evaluated with vertical or 45° oblique loading. To analyze the fringes, the root was divided into 6 parts: palatal cervical, palatal middle, palatal apical, vestibular cervical, vestibular middle, and vestibular apical. The formed fringes were photographed and quantified. Data were recorded and subjected to two-way ANOVA and Tukey's test (5%). SP (1.95±0.60) showed higher stress ($p<0.05$) compared to the others (CPC-0.52±0.74; CF-0.50±0.75, GF-0.23±0.48 and CGF-0.45±0.83). All posts showed high stress in apical third (CPC-1.40±0.65; SP-2.30±0.44, CF-1.80±0.45, GF-1.20±0.45, CGF-1.70±1.03) Low stress was found in cervical third (CPC-0.20±0.45; CF-0.00±0.00, GF-0.00±0.00, CGF-0.00±0.00), except by SP (1.90±0.65), which showed statistical difference ($p<0.05$). Customized post showed high stress concentration at the root and conventional glass fiber posts showed more favorable biomechanical behavior.

Key Words: customized glass fiber post, fiber post, stress, post and core, biomechanics.

Introduction

Endodontically treated teeth are generally weaker than sound teeth due to dental structural losses, pre-existing caries, and filling and root-canal preparations (1). When no alternative is available to retain the core, a post is necessary to provide adequate retention and support (1). Cast metal post/core has been for many years the treatment of choice because of their superior mechanical strength (2). However, the great difference between the metal and dentin elastic moduli may cause excessive stress concentration around the apices (3), which can lead to catastrophic failures (4,5). When this occurs, prognosis is poor and tooth extraction is almost guaranteed (6). Thus, fiber-reinforced composite posts (FRC) are alternatives to cast metal posts because their elastic moduli are similar to that of dentin, producing a favorable stress distribution and providing more aesthetic outcomes for anterior teeth (7).

Prefabricated metal posts were introduced in the 1970s (8). Compared to a single piece cast post-and-core, the use of a prefabricated post with a direct core is less invasive (9), less expensive (4) and does not require laboratory procedures (4), thereby simplifying the restoration process (9). A prefabricated post can be active or passive, depending on its ability to be retained. Active or screw posts are more retentive than passive posts, but introduce more stress into the root (10).

Nonmetal fiber posts gained popularity in the 1990s (1). Carbon fiber posts were the first to be developed and, given their improved properties, quickly became widely used. These posts are biocompatible, corrosion-resistant, bond to resin luting cement and have an elastic modulus similar to dentin (1). Unfortunately, carbon fiber posts do not allow a good aesthetic restoration with all-ceramic crowns. To compensate for this, glass and quartz fiber posts were introduced (1,11) which claimed the same advantages as carbon fiber posts, but with better esthetics (10,12,13). However, the use of prefabricated composite posts may become critical if restoration of a wide flared root cavity is entailed because a lot of cement has to be used to fix it (14). For this reason the technique of customizing the post was introduced recently and its distribution of stress in the root is still controversial (15).

There are studies analyzing the post and root fracture after a load is applied (2,3,5,9,16), but without analyzing the behavior of the involved forces. To analyze this behavior, the photoelastic analysis was introduced in dentistry to illustrate the distribution and the intensity of the stress, generally when prosthodontics are involved and/or associated with implants. However, it also showed efficiency to reproduce the stress caused by endodontic post in radicular dentin in different situations and using different post systems (17-21). The use of finite element analysis could also be used to obtain data to study stress development (22,23), however its use could not take into consideration the defects of a real model. The importance of the post stress analysis is to predict its clinical behavior, which takes many years to be achieved in a real situation (24). Besides this, there are only few studies about customized posts as it is a quite new technique (15). There is no information available on the stress distribution of this kind of post, which makes the clinical longevity and root fracture unpredictable.

The purpose of this study was to quantify and evaluate the distribution of stress in the root produced by different endodontic post types. The study hypothesis was that the stress distribution of the customized posts could be different from the other posts.

Material and Methods

This study was approved by the local Ethics Committee and registered in the national system of ethics in research (#CAAE-0089.0.078.000-08) prior to study development. Photoelastic models were made from a selected human canine, which had the crown removed and the root prepared to receive a size-3 fiber post using a sequence of Largo drills from #2 to #5. A bevel was made on the cervical margin of the tooth using bur #4137 (KG Sorensen, São Paulo, SP, Brazil). Individual trays of transparent acrylic resin (JET; Clássico Artigos Dentais Ltda, São Paulo, SP, Brazil) with polycarbonate pins (Pin-Jet; Angelus, Londrina, PR, Brazil) were made. The tooth was molded 25 times, using polyvinylsiloxane putty (Express STD; 3M ESPE, Saint Paul, MN, USA) for the external surface and light polyvinylsiloxane for the root canal mold. The molds were filled with epoxy resin (Flexible GII; Polipox Industria e Comércio Ltda, São Paulo, SP, Brazil) in a vacuum chamber.

The 25-photoelastic specimens were randomly divided into 5 groups (n=5) according to post type. Group CPC included one-piece cast post-and-core with a nickel-chromium alloy (Wirona Light; BEGO Bremer Goldschlägerei Wilhelm-Herbst GmbH&Co, Bremen, Germany) luted with zinc phosphate cement (SS White, Rio de Janeiro, RJ, Brazil). Group SP included size-3 screw posts (SS White), which was screwed into the photoelastic resin root together with the phosphate cement (SS White). Group CF included size-3 prefabricated carbon fiber posts (Reforpost; Angelus) luted with resin luting cement (Rely-X ARC; 3M ESPE). Group GF included size-3 prefabricated glass fiber posts (Reforpost, Angelus) luted with resin luting cement (Rely-X ARC; 3M ESPE). Group CGF included size-3 glass fiber customized posts (Reforpost; Angelus). In this group, a water-soluble gel (KY Gel; Johnson & Johnson, S.J. dos Campos, SP, Brazil) was used to isolate the photoelastic model. A composite resin (Filtek Supreme Plus, 3M ESPE) was adapted around the post, inserted in the canal and polymerized for 20 s. The specimen was removed from the photoelastic canal and polymerized for an additional 40 s. Irregularities were removed with Sof-Lex Pop-On discs (3M ESPE) before luting with resin luting cement (Rely-X ARC; 3M ESPE).

Both used types of Reforpost had the same shape and size. They were both parallel (∅1.5 mm) with tapered tip (∅0.11 mm). For the resin luting cement, a thin layer of adhesive (Adper Scotchbond multi purpose; 3M ESPE) was applied previous to the cement application and they were photoactivated for 20 s. The zinc phosphate and the resin luting cements were inserted using lentulo spiral filler attached to a low speed handpiece.

The lengths of the cores in Groups 2–5 were standardized using a transparent silicone tray molded to the shape of the coronary part of the one-piece cast post-and-core (Group 1). The coronary length of the post was set at 5 mm and the root at 13 mm. Cores were built with composite resin Filtek Supreme Plus (3M ESPE). Specimens were then

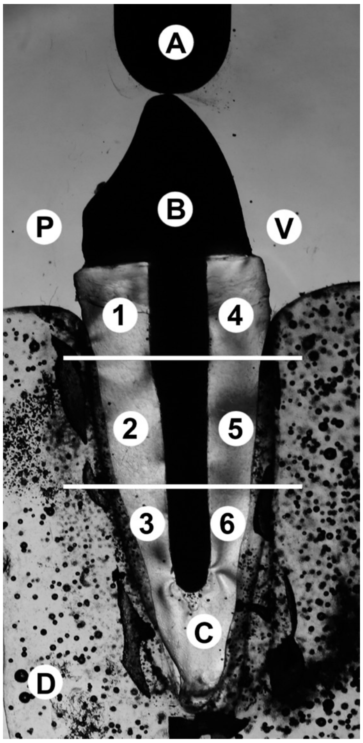

Figure 1. Photoelastic image of a cast metal post (B) under loading. Regions 1, 2, 3, 4, 5 and 6 represent the location of analysis; P represents the palatine region and V the vestibular region. Tip of the load application device (A). Photoelastic root simulation (C). Acrylic resin support (D).

stored in relative humidity environment at 37 °C for 24 h.

For analysis, the specimens were immersed in mineral oil. All the specimens were verified unloaded in the polariscope to verify previous fringe formation. This allowed the examiner to discard the previously formed fringes during load analysis. A load of 1.6 N was applied at the incisal edge of specimens positioned on a jig for vertical loading (V) or positioned at 2 mm bellow the incisal edge on the palatal surface for the 45° oblique load (O). The load applied was determined by a pilot study, which compared higher and lower loads and verified that 1.6 N promoted the best set of visible fringes. A polariscope, which consists in a sequence of polarized lens, made the fringes visible (Fig. 1), and the resulting color fringe patterns were recorded with a digital camera before and after load application.

The photos were visually examined to quantify and identify the location of stress throughout the endodontic post. Fringes were quantified considering a value of 1.00 (blue region) for a full fringe and intermediate values for incomplete fringes as follows: 0.25, red; 0.50, yellow and 0.75, green (25). Specimens were divided into six locations: the palatal cervical third (P1), palatal middle third (P2), palatal apical third (P3), vestibular cervical third (V4), vestibular middle third (V5), vestibular apical third (V6). For each location, the number corresponding to the maximum fringe order was recorded (Fig. 1). All analyses were performed by the same evaluator, which was calibrated (Kappa=0.857) and evaluated for intra-examiner agreement. Results were submitted to Ryan-Joiner and showed normality, then they were analyzed by two-way analysis of variance (ANOVA) followed by Tukey's test with 5% significance, according to the load direction: vertical and oblique.

Results

When the groups were analyzed for both loads regardless of location, screw posts displayed higher means ($p<0.05$) than the others, independent of load type (Table 1). When the location was analyzed independent of post, no statistical difference in stress was found (Table 2). Comparison of the results for location and tested groups together with oblique and vertical loading are detailed on the Tables 3 and 4, respectively.

Representative images of vertical and oblique load can be found in Figures 2 and 3, respectively. It was possible to visualize that independent of the load, glass fiber posts showed less stress and a more uniform distribution compared to the others. Customized glass fiber posts showed visually more stress than conventional post and core, carbon fiber and glass fiber, but less than the screw posts.

Discussion

This study showed that stress distribution of the customized posts was different from the other posts. When the unloaded state was analyzed after cementation, minimal or no stress was observed except for the screw post, consistent with previous studies (17,19,21). The minimum reminiscent stress was probably caused by the finger pressure applied during luting, because of the hydrostatic backpressure of the cement. For screw post group, stress was found around the screw thread, because the active post mechanically engages the threads in the dentin (10).

The choice for using zinc phosphate for metal posts and resin cement for fiber posts was to follow the manufacturers' recommendations. The use of an adhesive layer previous to the resin cement insertion improved the adhesion between photoelastic resin and the resin cement, generating a second interface. For zinc phosphate cement, micromechanical retention was observed with the photoelastic resin. In both cases, the luting acted similar to the real clinical situation. All the used kinds of post were similar in size and diameter to obtain standardization, but for adhesion to the root structure different size and shape acted similarly (11).

Table 1. Mean (standard deviation) of stress (MPa) generated in different posts regardless of location

	Vertical load	Oblique Load
CPC	0.45 (0.62) a	0.52 (0.75) a
SP	1.82 (0.56) b	1.95 (0.60) b
CF	0.42 (0.54) a	0.50 (0.74) a
GF	0.39 (0.58) a	0.23 (0.49) a
CGF	0.13 (0.37) a	0.45 (0.83) a

* Different letters in column indicate statistically significant differences ($p<0.05$).

Table 2. Mean (standard deviation) of stress (MPa) generated in different location regardless of type of post

	Vertical load	Oblique Load
P1	0.40 (0.69) a	0.42 (0.82) a
P2	0.40 (0.70) a	0.38 (0.73) a
P3	1.13 (0.74) a	0,97 (0.97) a
V4	0.44 (0.79) a	0.54 (0.83) a
V5	0.48 (0.78) a	0.40 (0.76) a
V6	1.00 (0.81) a	1.68 (0.70) a

* Different letters in column indicate statistically significant differences ($p<0.05$).

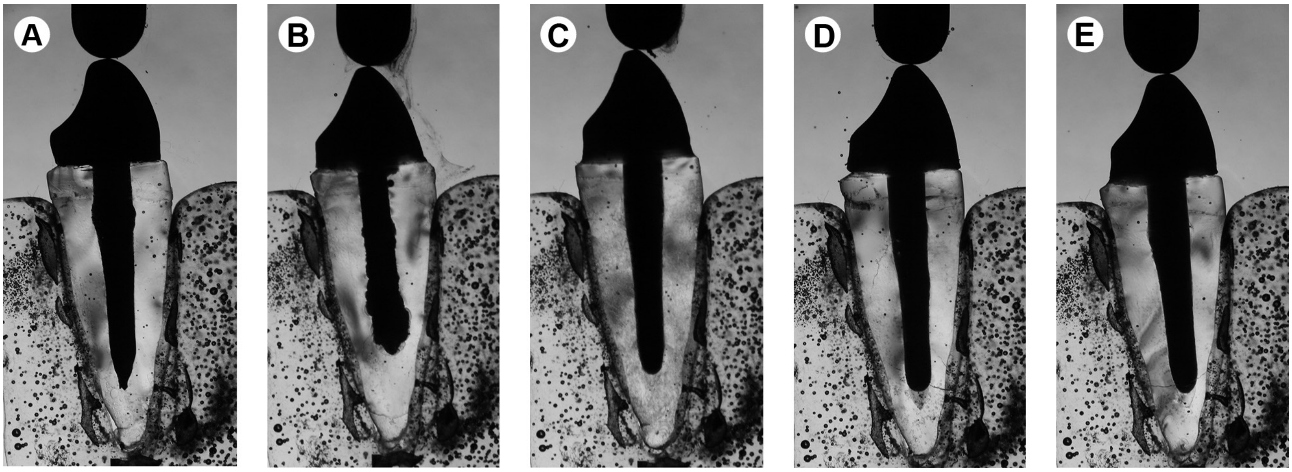

Figure 2. Photoelastic image of G1: cast post-and-core (A); G2: screw post (B); G3: carbon fiber post (C); G4: glass fiber post (D); and G5: customized glass fiber post (E) when vertical load was applied.

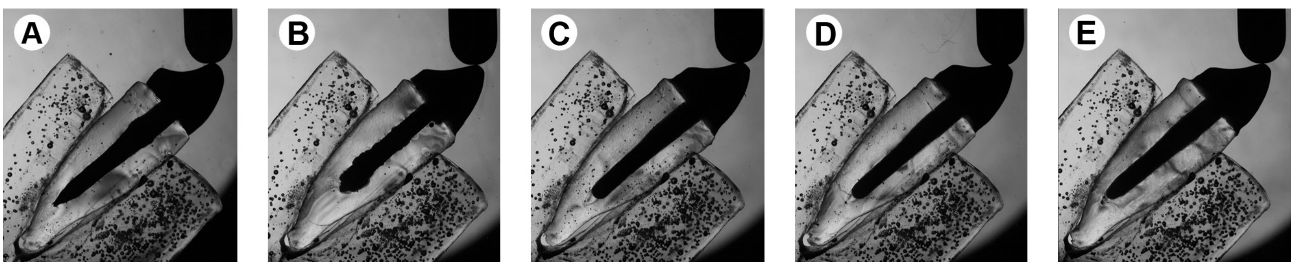

Figure 3. Photoelastic image of G1: cast post-and-core (A); G2: screw post (B); G3: carbon fiber post (C); G4: glass fiber post (D); and G5: customized glass fiber post (E) when oblique load was applied.

Table 3. Mean (standard deviation) of stress (MPa) generated in different locations with oblique loading

Group	P1	P2	P3	V4	V5	V6
CPC	0.20 (0.44) aAB	0.00 (0.00) aA	1.15 (0.96) abAB	0.20 (0.27) aAB	0.20 (0.44) aAB	1.40 (0.65) aB
SP	1.9 (0.65) bA	1.70 (0.44) bA	2.30 (0.44) bA	1.80 (0.75) bA	1.70 (0.75) bA	2.30 (0.44) aA
CF	0.00 (0.00) aA	0.20 (0.44) aA	0.60 (0.54) abA	0.30 (0.67) aA	0.10 (0.22) aA	1.80 (0.44) aB
GF	0.00 (0.00) aA	0.00 (0.00) aA	0.10 (0.224) aA	0.10 (0.224) aA	0.00 (0.00) aA	1.20 (0.44) aA
CGF	0.00 (0.00) aA	0.00 (0.00) aA	0.70 (0.83) abAB	0.30 (0.67) aA	0.00 (0.00) aA	1.70 (1.03) aB

Different small letters in column or different capital letters in row indicate statistically significant differences ($p<0.05$).

Table 4. Mean (standard deviation) of stress (MPa) generated in different locations with vertical loading

Group	P1	P2	P3	V4	V5	V6
CPC	0.20 (0.44) aA	0.00 (0.00) aA	1.40 (0.54) bB	0.00 (0.00) aA	0.50 (0.50) aA	0.60 (0.54) aA
SP	1.60 (0.41) bA	1.60 (0.54) bA	2.00 (0.50) bA	1.70 (0.75) bA	1.80 (0.67) bA	2.20 (0.45) bA
CF	0.00 (0.00) aA	0.20 (0.44) aA	0.90 (0.22) abA	0.30 (0.67) aA	0.10 (0.22) aA	1.00 (0.50) aA
GF	0.20 (0.44) aA	0.20 (0.44) aA	1.05 (0.71) abA	0.20 (0.44) aA	0.00 (0.00) aA	0.70 (0.57) aA
CGF	0.00 (0.00) aA	0.00 (0.00) aA	0.30 (0.44) aA	0.00 (0.00) aA	0.00 (000) aA	0.50 (0.70) aA

Different small letters in column or different capital letters in row indicate statistically significant differences ($p<0.05$).

The stress observed after vertical loading (Fig. 2) for one-piece cast post-and-core was higher in the apical third. This finding is likely due to the high elastic modulus of metal posts (6). This makes the system stiff, able to resist forces without distortion but unable to absorb stress, transmitting the load directly to the root. The higher stress found in the apical third of these posts may be related to root fractures, which occur not infrequently when a metal post is used (5,9). As expected, stress was distributed over the entire screw post, consistent with Caputo and Hokama (17). Active screws develop stress during post insertion that is aggravated during load application. The higher resulting stress may be a cause for concern when a screw post is used.

The greater flexibility and lower stiffness of fiber posts promote a uniform stress distribution in the tooth, creating a mechanically homogeneous unit and reducing the risk of root fracture (4). The prefabricated glass fiber post was stiff (23), with an elastic modulus (14) more similar to dentin than that of the prefabricated carbon fiber post. The glass fiber customized post led to a superior fit to the root canal walls, reducing the required amount of cement. This could reduce the polymerization stress and the number of bubbles in the cement, favoring post retention and preventing adhesive failure (15). However, visual analysis of the specimens (Fig. 2D) revealed a higher stress on the root compared to a regular prefabricated glass fiber post (Fig. 2E). This result was perhaps due to the higher hydrostatic pressure of the cement, which generates stress during post insertion. This stress probably does not dissipate with time (20). Therefore, the greater the stress on insertion, the higher the accumulated stress will be when the tooth is in function. Despite this, customized posts evaluated over a 3-year observation period showed that the placement of prefabricated or customized posts provide a significant contribution to the survival of pulpless restored teeth (24).

When glass fiber, carbon fiber and customized glass fiber post were compared, a higher stress concentration was found in the vestibular location (L4) of the carbon fiber and customized glass fiber posts than in the prefabricated glass fiber post. This perhaps resulted from the lower stiffness of the prefabricated glass fiber post compared with the prefabricated carbon fiber post (23). The increased amount of resin and reduced amount of resin luting cement in the glass fiber customized post presumably made the system (resin+post+cement) more rigid than the post and cement system, decreasing the vestibular stress concentration. The analysis was from the perspective of the post stress, regardless the stress from the core (21), which led to a more precise analysis of the post.

High stress with oblique loading (Fig. 3) in the apical third of the posts was found (14), except by the screw post that showed no difference in the different locations. Visual analysis revealed that the prefabricated glass fiber post introduced better biomechanical properties because the stress was more uniform along the post (22). The oblique forces, which are the most common forces during mastication, lead to a higher stress on the apical region (Table 3). Considering that fractures in coronal thirds were deemed repairable and fractures in cervical and medium third were deemed catastrophic (5), the metallic posts (CPC and SP – Table 3) showed higher stress in that area, probably due to its higher rigidity, which leads to a worse prognostic for the teeth.

A limitation of this study is the absence of the crown, with the load being applied directly on the core. This scenario could have produced a different biomechanical effect from the presence of crown. However, measuring the stress by a photoelastic resin while applying loads directly on the post or on the core resin, Cooney et al. (19) found that the stress distribution was similar but less intense in the group with core resin.

Photoelastic stress analysis concerns visual observations based on the ability of transparent plastic materials to exhibit interference fringes in a polarized light when stressed (18). The fringes that were observed represent zones of concentrated stress intensity and may be identified by a sequence of a repeating color bands: red, yellow, green and blue. These color fringes allow evaluating the post systems by interpreting the obtained color stress patterns. More color fringes indicate more stress. The physical and mechanical properties of the natural tooth are not exactly the same of the photoelastic resin. In this way, the stress raw value cannot be considered, but the distribution of stress and the differences of stress intensity of the different restorative post systems used in this work can be used to predict their clinical performance.

In conclusion, the ideal dental situation arises when stress in the root is minimized. Metallic posts showed higher stress in the apical area during oblique forces, which clinically represents a worse teeth prognostic. Customized post showed high stress concentration at the root compared to conventional glass fiber posts. A better stress behavior may increase the longevity of the restoration and reduce the chance of a catastrophic failure, making the prefabricated glass fiber posts the best choice for restoring endodontically compromised teeth, despite the study limitations and considering the present results.

Resumo

Pinos endodônticos são necessários para promover retenção e suporte adequados quando a estrutura dental remanescente não é suficiente para reter o núcleo. Há diferentes materiais e técnicas para construir o núcleo, mas não há consenso sobre o qual promove a melhor distribuição de tensão na estrutura dental remanescente. O objetivo deste trabalho foi quantificar e avaliar a distribuição de tensões produzidas nas

raízes por pinos de fibra de vidro customizados quando comparados a diferentes pinos endodônticos. Vinte e cinco raízes simuladas em resina fotoelástica foram confeccionadas e divididas em 5 grupos: CPC, núcleo metálico fundido, SP, pino rosqueável; CF, pino de fibra de carbono; GF, pino de fibra de vidro; CGF, pino de fibra de vidro customizado. Depois da cimentação dos pinos de CPC e SP com cimento de fosfato de zinco e dos pinos de CF, GF e CGF com cimento resinoso, núcleos em resina foram feitos para os grupos 2-5. Os espécimes foram avaliados com carga vertical ou oblíqua a 45º. Para analisar as franjas, a área da raiz foi dividida em 6 partes: palatina cervical, palatina média, palatina apical, vestibular cervical, vestibular média e vestibular apical. As franjas formadas foram fotografadas e quantificadas. Os dados foram gravados e submetidos à ANOVA de dois fatores e ao teste de Tukey (5%). SP (1,95±0,60) mostrou maior tensão (p<0,05) quando comparado com os demais (CPC - 0,52±0,74; CF - 0,50±0,75, GF - 0,23±0,48, CGF - 0,45±0,83). Todos os pinos mostraram maior tensão no terço apical (CPC - 1,40±0,65; SP - 2,30±0,44, CF – 1,80±0,45, GF – 1,20±0,45, CGF – 1,70±1,03) Menor tensão foi encontrado no terço cervical (CPC – 0,20±0.45; CF – 0,00±0 00, GF – 0 ,0±0,00, CGF – 0,00±0,00), exceto pelo SP (1,90±0,65), que não apresentou diferença estatística (p<0,05). Pinos customizados de fibra de vidro mostraram maior concentração de estresse na raiz quando comparados com pinos convencionais de fibra de vidro, que se mostraram com comportamento biomecânico mais favorável.

References

1. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004;30:289-301.
2. Silva GR, Santos-Filho PC, Simamoto-Junior PC, Martins LR, Mota AS, Soares CJ. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. Braz Dent J 2011;22:230-237.
3. Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89:360-367.
4. Barjau-Escribano A, Sancho-Bru JL, Forner-Navarro L, Rodríguez-Cervantes PJ, Pérez-González A, Sánchez-Marín FT. Influence of prefabricated post material on restored teeth: fracture strength and stress distribution. Oper Dent 2006;31:47-54.
5. Martelli Jr H, Pellizzer EP, Rosa BT, Lopes MB, Gonini Jr A. Fracture resistance of structurally compromised root filled bovine teeth restored with accessory glass fibre posts. Int Endod J 2008;41:685-692.
6. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y, et al.. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dent Mater J 2006;25:145-150.
7. Rosa RA, Barreto MS, Moraes R do A, Broch J, Bier CAS, Só MVR, et al.. Influence of endodontic sealer composition and time of fiber post cementation on sealer adhesiveness to bovine root dentin. Braz Dent J 2013;24:241-246.
8. Baraban DJ. A simplified method for making posts and cores. J Prosthet Dent 1970;24:287-297.
9. Gu XH, Kern M. Fracture resistance of crowned incisors with different post systems and luting agents. J Oral Rehabil 2006;33:918-923.
10. Fernandes AS, Shetty S, Coutinho I. Factors determining post selection: a literature review. J Prosthet Dent 2003;90:556-562.
11. Poskus LT, Sgura R, Paragó FEM, Silva EM, Guimarães JGA. Influence of post pattern and resin cement curing mode on the retention of glass fibre posts. Int Endod J 2010;43:306–311.
12. Rippe MP, Santini MF, Bier CA, Borges AL, Valandro LF. Root canal filling: fracture strength of fiber-reinforced composite-restored roots and finite element analysis. Braz Dent J 2013;24:619-625.
13. Braga NM, Souza-Gabriel AE, Messias DC, Rached-Junior FJA, Oliveira CF, Silva RG, et al.. Flexural properties, morphology and bond strength of fiber-reinforced posts: influence of post pretreatment. Braz Dent J 2012;23:679-685.
14. Genovese K, Lamberti L, Pappalettere C. Finite element analysis of a new customized composite post system for endodontically treated teeth. J Biomech 2005;38:2375-2389.
15. Grandini S, Sapio S, Simonetti M. Use of anatomic post and core for reconstructing an endodontically treated tooth: a case report. J Adhes Dent 2003;5:243-247.
16. Furuya Y, Huang SH, Takeda Y, Fok A, Hayashi M. Fracture strength and stress distributions of pulpless premolars restored with fiber posts. Dent Mater J 2014;33:852-858.
17. Caputo AA, Hokama SN. Retention and stress-distributing characteristics of a new dowel system. J Prosthet Dent 1984;51:652-655.
18. Cohen BI, Pagnillo M, Musikant BL, Deutsch AS. Comparison of the retentive and photoelastic properties of two prefabricated endodontic post systems. J Oral Rehabil 1999;26:488-494.
19. Cooney JP, Caputo AA, Trabert KC. Retention and stress distribution of tapered-end endodontic posts. J Prosthet Dent 1986;55:540-546.
20. Musikant BL, Deutsch AS. A new prefabricated post and core system. J Prosthet Dent 1984;52:631-634.
21. Yaman P, Thorsteinsson TS. Effect of core materials on stress distribution of posts. J Prosthet Dent 1992;68:416-420.
22. Duret B, Duret F, Reynaud M. Long-life physical property preservation and postendodontic rehabilitation with the Composipost. Compend Contin Educ Dent Suppl 1996;S50-S56.
23. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor. Dent Mater 2005;21:709-715.
24. Cagidiaco MC, Garcia-Godoy F, Vichi A, Grandini S, Goracci C, Ferrari M. Placement of fiber prefabricated or custom made posts affects the 3-year survival of endodontically treated premolars. Am J Dent 2008;21:179-13084.
25. Lopes MB, Valarini N, Moura SK, Guiraldo RD, Gonini Junior A. Photoelastic analysis of stress generated by a silorane-based restoration system. Braz Oral Res 2011;25:302-306.

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