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Fracture resistance of endodontically treated teeth and restored with different fiber posts in distinct diameters

Resistência à fratura de dentes tratados endodonticamente e restaurados com diferentes pinos de fibra em diâmetros distintos

Resistencia a la fractura de dientes tratados endodónticamente y restaurados con diferentes postes de fibra en diferentes diâmetros

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Abstract
Objective: The aim of this in vitro study was to evaluate the fracture resistance of endodontically treated teeth restored with different intraradicular posts (carbon fibers, glass, or quartz) with varying post diameters (narrow, medium, or large). Methodology: One hundred and twenty bovine incisors were endodontically treated and the post space was prepared. The teeth were classified according to distinct diameters post space [Narrow (0.91-1.49mm), Medium (1.5-2.08mm), Large (2.09mm-2.67mm)] and randomly allocated to four restorative treatments: control (CO) - without post; and glass fiber (GF), carbon (CF) or quartz (QF) posts. The posts were cemented with dual-cure resin cement (Duo Link, Bisco, Schaumburg, United States) and the coronary portion was reconstructed with dual-cure resin composite (Bis-Core, Bisco, Schaumburg, United States). Fracture resistance values (N) were analyzed by two-way ANOVA and Bonferroni test (α=0.05). Results: The carbon fiber post (CF) was mechanical behavior similar to the other evaluated posts, regardless of the diameter. The control group (without post) showed the highest values of fracture resistance (1013.8 - 1127.2 N) in relation to the groups with the different evaluated posts (236.1 - 615.1 N). Within the same material, the diameter influenced the fracture strength only of the quartz fiber post, with the highest values for diameter large. Conclusion: A larger diameter only gives greater fracture resistance for QF; CF posts have similar resistance to other posts, regardless of diameter; and for large diameter, the type of post used does not differ in fracture resistance.
Keywords: Tooth, nonvital; Post and core technique; Dental restoration, permanent; Compressive strength; Tooth fractures.

Resumo
Objetivo: O objetivo deste estudo in vitro foi avaliar a resistência à fratura de dentes tratados endodonticamente restaurados com diferentes pinos intrarradiculares (fibras de carbono, vidro ou quartzo) com diâmetros variados (estreito, médio ou grande). Metodologia: Cento e vinte incisivos bovinos foram tratados endodonticamente e o espaço do pino foi preparado. Os dentes foram classificados de acordo com os diâmetros distintos do espaço do pino [Estreito (0,91-1,49mm), Médio (1,5-2,08mm), Grande (2,09mm-2,67mm)] e alocados aleatoriamente em quatro tratamentos restauradores: controle (CO) - sem pinos; e pinos de fibra de vidro (GF), carbono (CF) ou quartzo (QF). Os pinos foram cimentados com cimento resinoso de cura dual (Duo Link, Bisco, Schaumburg, Estados Unidos) e a porção coronária foi reconstruída com resina composta de cura dual (Bis-Core, Bisco, Schaumburg, Estados Unidos). Os valores de resistência à fratura (N) foram analisados por ANOVA a dois fatores e teste de Bonferroni (α=0,05). Resultados: O pino de fibra de carbono (CF) apresentou comportamento mecânico semelhante aos demais pinos avaliados, independente do diâmetro. O grupo controle (sem pino) apresentou os maiores valores de resistência à fratura (1013,8 - 1127,2 N) em relação aos grupos com os diferentes pinos avaliados (236,1 - 615,1 N). Dentro do mesmo material, o diâmetro influenciou a resistência à fratura apenas do pino de fibra de quartzo, com os maiores valores para diâmetro grande. Conclusão: Um diâmetro maior só confere maior resistência à fratura para QF. Os pinos CF apresentam resistência semelhante a outros pinos, independente do diâmetro. Para diâmetro grande, o tipo de pino utilizado não difere na resistência à fratura.
Palavras-chave: Dente não vital; Técnica para retentor intrarradicular; Restauração dentária permanente; Força compressiva; Fraturas dos dentes.

Resumen
Objetivo: El objetivo de este estudio in vitro fue evaluar la resistencia a la fractura de dientes tratados endodónticamente restaurados con diferentes postes intrarradiculares (fibra de carbono, vidrio o cuarzo) con diferentes diámetros de poste (estrecho, mediano o grande). Metodología: Ciento veinte incisivos bovinos fueron tratados endodónticamente y se preparó el espacio del poste. Los dientes se clasificaron según distintos diámetros post espacio [Estrecho (0,91-1,49 mm), Medio (1,5-2,08 mm), Grande (2,09 mm-2,67 mm)] y asignados aleatoriamente a cuatro tratamientos restauradores: control (CO) - sin correo; y postes de fibra de vidrio (GF), carbono (CF) o cuarzo (QF). Los postes se cementaron con cemento de resina de curado dual (Duo Link, Bisco, Schaumburg, Estados Unidos) y la porción coronaria se reconstruyó con composite de resina de curado dual (Bis-Core, Bisco, Schaumburg, Estados Unidos). Los valores de resistencia a la fractura (N) se analizaron mediante ANOVA de dos vías y prueba de Bonferroni (α=0.05) Resultados: El poste de fibra de carbono (CF) tuvo un comportamiento mecánico similar a los demás postes evaluados, independientemente del diámetro. El grupo control (sin poste) presentó los mayores valores de resistencia a la fractura (1013,8 - 1127,2 N) en relación a los grupos con los diferentes postes evaluados (236,1 - 615,1 N). Dentro del mismo material, el diámetro influyó en la resistencia a la fractura únicamente del poste de fibra de cuarzo, con los valores más altos para el diámetro grande. Conclusión: A mayor diámetro solo se obtiene mayor resistencia a la fractura para QF; Los postes CF tienen una resistencia similar a otros postes, independientemente del diámetro; y para diámetro grande, el tipo de poste utilizado no difiere en la resistencia a la fractura.
Palabras clave: Diente no vital; Técnica de perno muñón; Restauración dental permanente; Fuerza compresiva; Fracturas de los dientes.

1. Introduction

Endodontically treated teeth often present with extensive coronary damage resulting from caries activity, previous restorations, trauma and/or due to the coronal access for endodontic treatment itself (Schestatsky et al., 2019). This clinical situation compromises the retention of coronary reconstruction and represents a great challenge for clinicians. The risk in restoring teeth with several damage occurs because the fracture resistance of these dental elements is dependent on the amount of remaining healthy dental structure (Figueiredo et al., 2015; Martins et al., 2021; Shu et al., 2018).

Despite the constant advances in Adhesive Dentistry, the universally accepted model and still indicated for the prosthetic restoration of dental elements in these conditions involves the use of intraradicular posts, as it allows the restoration of the biomechanical characteristics necessary to retain the restoration (Dotto et al., 2022; Signore et al., 2009).

The use of prefabricated posts of different materials has been widely accepted due to the advantages related to ease of use, placement in a single session, and the possibility of cost reduction by eliminating the laboratory phase (de Oliveira et al., 2008; Tsintsadze et al., 2022). Besides, composites and posts with close elasticity modules have demonstrated a good ability to interact between surfaces and alternative techniques with easy handling. This allows better adaptations of these composites along with the post-core interface and from the post to the canal walls, without the presence of bubbles or cracks in this interface, which would negatively affect the strength of the structure and increase the risk of fracture (Meng et al., 2018).

The elasticity modulus, stiffness, and thermal expansion coefficient are physical properties of posts and composites that must be close to the properties of dentin so that the forces of mastication can be dissipated along the post and transmitted to the root, limiting stress on the dental remnant (Sorrentino et al., 2016; Tsintsadze et al., 2022). Thus, several materials have been used in the manufacture of these posts such as glass fibers wrapped by resinous matrix (Barreto et al., 2012; Boschian Pest et al., 2006), carbon fiber also joined to a resinous matrix (Ferrari et al., 2001; Palepwad & Kulkarni, 2020; Rodríguez-Cervantes et al., 2007), and quartz (Galhano et al., 2005; Kremeier et al., 2008; Parisi et al., 2015; Vadavadagi et al., 2017). Differences in the shape and surface of the posts have also been proposed in order to increase the retention and resistance of the post/tooth set (Santos-Filho et al., 2014).

The ideal conditions for sizing the channel for post placement have been widely studied, as post dimensions can also influence resistance to root fracture, since larger posts can lead to greater losses of mineralized structure (Dikbas et al., 2007; Santini et al., 2014). For this reason, there is a recommendation that the post should not exceed one third of the mesiodistal diameter of the root (de Oliveira et al., 2008; Munari et al., 2019), which justifies the variation in the diameter of the posts offered in the different systems.

However, anatomical variations are frequently observed in clinical practice, generating variations in the diameter of the root canal space and, consequently, in the intraradicular retainers (Martins et al., 2021; Schestatsky et al., 2019; Shu et al., 2018). The literature remains unclear on the effects of variation in the dimensions of prefabricated posts on the biomechanical performance of the restored tooth (de Oliveira et al., 2008; Martins et al., 2021), so that the decisions of clinicians about this have been made empirically. Thus, the aim of this study was to evaluate the fracture resistance of teeth restored with prefabricated posts of different materials after variation in the post's diameters. The following null hypotheses were tested: H1 - different intraradicular posts have no effect on fracture resistance of endodontically treated teeth, and H2 - the diameter of the post does not affect fracture resistance.

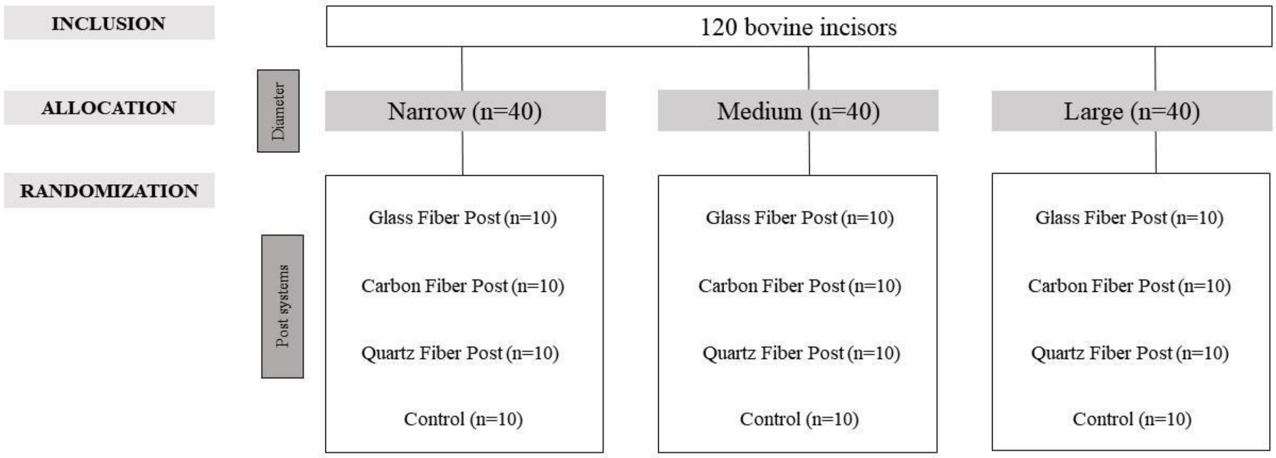
2. Methodology

Experimental Design

This in vitro study evaluated the fracture resistance of endodontically treated teeth that received coronary reconstruction with cementation of different intraradicular posts of different diameters, compared to the control situation of teeth without endodontic treatment and restored with composite resin without a post.

Glass fiber posts (White Post DCE, FGM, Joinvile, Brazil), carbon fiber posts (Refor Post, Angelus, Londrina, Brazil), and quartz fiber posts (DT Light Post, Bisco, Schuamburg, United States) were used in the present study. The experimental design is illustrated in Figure 1. Minimum sample required (n = 10/group) was calculated with the G Power software, considering the effect size of the previous study (Wandscher et al., 2015), significance level of 5% and 95% of the test power.

Figure 1. Flowchart of the experimental design.



Source: Authors.

Specimen preparation

120 bovine incisors were used in this study. After mechanical cleaning of the teeth using periodontal curettes and prophylaxis with pumice and Robson's brush, the teeth were stored in 0.1% thymol solution for 24 hours. Teeth with a diameter greater than 7.51 mm (Boschian Pest et al., 2006) were excluded, confirmed with the use of a digital caliper. In addition, radiographs were taken and those teeth with incomplete rhizogenesis, root curvature or some malformation in the root canal were also excluded.

The selected teeth were sectioned in the transverse direction with double-sided diamond disc under refrigeration, at 14 and 19 mm from the apex for the experimental and control groups, respectively. Then, the surface of the sectioned area was leveled with 4138F diamond tips (KG Soresen, Cotia, Brazil). After sectioning, the elements had the channel light measured with a digital caliper in the mesiodistal direction.

Groups

The measurement of the sectional teeth canal light served as a parameter for the composition of the groups according to the diameter of the root canals. For this, an amplitude value was obtained from the ratio between the difference of the largest and smallest diameter obtained by the number of diameters to be classified (Figueiredo et al., 2015). The amplitude value for each group (0.58) served for the composition of the groups, as shown in Table 1.

Table 1. Limit values of the diameters of the canals' lumen for the formation of the small, medium, and large experimental groups.

Group	**Diameter limits**[1]	
	Low	Upper
Narrow	0.91 mm	1.49 mm
Medium	1.5 mm	2.08 mm
Large	2.09 mm	2.67 mm

[1] Amplitude of each group - 0.58 mm. Source: Authors.

Endodontic Treatment

With the roots sectioned, the beginning of root canal treatment eliminated the coronary opening stage. The endodontic instrumentation followed the sequence of Gattes Glidden cutters compatible with the files that would be used in a conventional instrumentation. This method aimed to generate the minimum damage to the inner walls of the roots during the instrumentation phase.

Continuous irrigation of the radicular canal during instrumentation with the Gattes Glidden cutters (# 2, # 3, and # 4) was performed with 2.5% Sodium Hypochlorite. To dry the ducts, absorbent paper tips were used. The channels were prepared up to the limit of 1 mm below the root apex and filled with a main cone of gutta percha of caliber corresponding to that of the last Gattes Glidden cutter used in instrumentation and filling cement (Sealer 26, Dentsply, Buenos Aires, Argentina).

Post cementation

Each root was 11 mm in the length of its unobstructed canal, maintaining 3 mm of obturator material in the apical portion (Barreto et al., 2012). Desobturation was performed with cutters provided by the post manufacturers and following the recommended technical sequence (Barreto et al., 2012). The process was carried out under refrigeration. After unblocking, the conduits were irrigated with distilled water, aspiration performed with endodontic cannulas and drying with absorbent paper cones.

Then, the conduits were conditioned with 37% phosphoric acid gel (Condac 37, FGM, Joinville, SC, Brazil) for 15 seconds, washing with air/water spray for 30 seconds and drying with an endodontic cannula and absorbent paper cones. The cementation of the posts in the root canals was performed with dual-setting resin cement (Duo Link, Bisco, Schaumburg, United States) associated with a conventional adhesive system (Scotch Bond Multiporpuse, 3M, Saint Paul, United States). The handling and application of the adhesive system and resin cement followed the manufacturers' recommendations. The cement was introduced into the space prepared for the post and applied to the surface of the posts with the aid of applicator tips. Then, the posts were passively inserted into the channels, the excess resin cement removed with micro-applicators and the photoactivation (600 mW/cm^2) performed so that the light fell on the coronary portion for 40 seconds, parallel to the long axis of the post (Ultraled, Dabi Atlante, Ribeirão Preto, Brazil).

All posts used in the study were standardized in terms of length, being sectioned with a diamond disc under refrigeration at 16 mm from the apex. The morphological characteristics of each commercial brand were considered when specimens were prepared following the manufacturers' guidelines for the intraradicular preparation of each dental structure.

Crown restoration

To restore the coronary portion of each specimen, a composite resin with dual cure (Bis-Core, Bisco, Schaumburg, United States) was used specifically for the construction of filling cores. Matrices were obtained from a single element previously molded with elastomer (Speedex, Vigodent Coltene, Bonsucesso, Brazil) and duplicated with plaster type IV (Durone, Dentsply, Petrópolis, Brazil) that served as guides for the construction of the filling cores. A matrix was made for each group, according to the diameter (small, medium, or large). After photoactivation of the resin (Ultraled, Dabi Atlante, Ribeirão Preto, Brazil; 600 mW/cm^2) for 40 seconds, preparation and polishing of the preparation were carried out under air / water spray cooling, with diamond tips 4138F and 3148F (KG Soresen, Cotia, Brazil).

Afterwards, the elements were molded (Condensation silicone; Speedex, Vigodent Coltene, Bonsucesso, Brazil), models were obtained (Plaster type IV; Durone, Dentsply, Petrópolis, Brazil) and the metal coppings were obtained from nickel chrome alloy (Fitcast SB, Valencia, United States). The elements of the control group were sectioned at 19 mm to simulate an intact coronary portion of 5 mm, corresponding to the height of the coronary portion constructed with resin in the prepared elements. This was done to standardize the lengths of the posts and coronary portions without preparation.

Static test of fracture strength

The specimens of all groups were placed in PVC cylinders (Tigre S.A., Escada, Brazil) parallel to the long axis of the cylinders and centralized vertically. The cylinders were filled with chemical curing acrylic resin (Vipi Flash, Pirassununga, Brazil) so that the roots remained immersed in 11 mm of total length. Thus, 3 mm was kept between the margin of the acrylic resin and the margin of the cervical end of the preparation. The cylinders with the assembled specimens were stored in distilled water at 37 °C for 24 hours.

The specimens were subjected to fracture resistance testing in a universal testing machine (Shimadzu, Kyoto, Japan), by compression load. Each copping was based on the respective preparation at the time of the mechanical test. The specimens were positioned at 45° in relation to the horizontal plane, maintaining an angle of 135° in relation to the axis of application of the force, with a speed of 0.5 mm/min. The machine ceased the force automatically when there was a system failure (post fracture, tooth fracture or displacement of the core) and the maximum fracture force was recorded in Newtons (N).

Statistical analysis

The fracture strength values were described as measures of central position and dispersion. The analysis of variance (ANOVA) was used for comparison among the groups. This model is applied for the normal distribution of the residue with mean zero and constant variance, verified by the Shapiro-Wilk and Levene tests. The differences pointed out by two-way ANOVA were identified by the Bonferroni test. A 5% level of significance was considered. All analyzes were conducted using Statistical Package for the Social Sciences (IBM SPSS Version 22.0, Chicago, IL, USA.)

3. Results

Two-way ANOVA identified a significant effect for the post type ($p < 0.001$), and for the diameter ($p < 0.001$). However, the post X diameter interaction had no significant effect on fracture resistance ($p = 0.154$).

In general, the mechanical behavior of the carbon fiber post (CF) was similar to the other evaluated posts, regardless of the diameter. However, the GF and QF posts only had similar fracture resistance to each other in the large diameter. In addition, the control group (without post) showed the highest values of fracture resistance in relation to the groups with the different evaluated posts.

Within the same material, the diameter significantly influenced the fracture strength values only for the quartz fiber post. In this material, significantly higher resistance was observed for the large diameter. In the restorative condition without the use of a post (control), the diameter of the root canal space also had no significant effect on fracture resistance. All data of multiple comparisons for the two factors evaluated are shown in Table 2.

Table 2. Mean values ±standard error of fracture resistance (N) for all groups in each diameter.

Post system	**Diameter**		
	Narrow	*Medium*	*Large*
Glass Fiber Post	604.7 ±92.2^{Ba}	466.1 ±95.2^{Ba}	594.2 ±93.5^{Aa}
Carbon Fiber Post	476.7 ±65.1^{ABa}	397.2 ±55.7^{ABa}	570.7 ±86.9^{Aa}
Quartz Fiber Post	397.3 ±83.7^{Aa}	236.1 ±32.1^{Aa}	615.1 ±88.1^{Ab}
Control	1123.5 ±181.7^{Ca}	1013.8 ±83.1^{Ca}	1127.2 ±95.9^{Ba}

$^{A-a}$ Different uppercase letters (vertically) and different lowercase letters (horizontally) mean significantly different (Bonferroni Test; $P<0.05$).
Source: Authors.

4. Discussion

This study investigated the effect of variations in the diameter of different intraradicular posts on fracture resistance of endodontically treated teeth. The variation in diameter affected the fracture resistance of one of the evaluated materials (quartz fiber post) and in all the studied diameters, resistance variations associated with the evaluated restorative strategies were observed. Thus, both null hypotheses were rejected.

By varying the dimensions of the posts, previous experiments found a significant influence on the fracture resistance of teeth restored with metal posts (Rodríguez-Cervantes et al., 2007; Santini et al., 2014; Santos-Filho et al., 2014). For teeth restored with posts with mechanical properties close to the dental structure, the influence of the variation in dimensions is not yet fully proven, for this reason, in this experiment, the use of posts that presented an elasticity module close to the tooth was standardized (Galhano et al., 2005).

The control group showed the highest fracture resistance averages in all diameters, confirming the findings in the literature in which the healthy or minimally prepared dental element showed higher fracture resistance averages, when compared with restored elements with or without intraradicular retainers (Marchi et al., 2008; Sorrentino et al., 2016). The values observed for fracture in the experimental groups were significantly lower than in the control group, suggesting that the wear of the mineralized, coronary and root structure, can significantly influence the resistance of these elements (Marchi et al., 2008; Sorrentino et al., 2016).

Among the experimental groups, the GF and carbon posts showed similar fracture resistance values. In addition, the GF demonstrated significantly higher strength values than QF. Considering that the preparation of the specimens followed the same technical sequence for all systems, it can be suggested that the differences between the mean values are related to the mechanical properties of each system (Dotto et al., 2022; Galhano et al., 2005). Thus, it is suggested that the elasticity modulus of glass and carbon fibers, as they resemble dentin elasticity modulus, may be a preferable system to be used in relation to the quartz fiber post. However, other factors such as clinical longevity, material cost and demand for clinical time need to be considered. Further studies to assess these variables are encouraged.

The diameter of the post, in each system, had a significant effect on fracture resistance, in contrast to the findings of Rodríguez-Cervantes et al. (2007) who did not observe the influence of the diameter of retainers with an elasticity module close to that of dentin, in the maximum fracture strength. For Marchi et al. (2008) there is still no consensus among the authors on the influence of the diameter of fiber posts on the fracture resistance of the roots, but these authors observed that the performance of these structures also depends on the quality of the bond between the resinous adhesive materials and the wall channel. It is impossible to disregard the influence of the adhesive cementation procedure of the evaluated post systems. However, as in this study there were no variations in the cementation protocols, it is suggestive that the variations in the maximum fracture strength were in fact of the variables under study. Therefore, new studies that investigate which cementation protocols provide better results associated with different post systems with variable diameters are desirable.

The increase in the post diameter gave a significant increase in fracture resistance for the quartz fiber posts. Quartz fiber posts are quite resistant to higher loads due to their higher modulus of elasticity (Galhano et al., 2005; Kremeier et al., 2008; Parisi et al., 2015). Thus, the increase in the post diameter was directly proportional to the increase in fracture resistance only for this post system. However, it is also suggested that, during the load application, this type of post transmits more stresses to the tooth structure. Thus, a slow crack growth causes a successive failure of the dentin-post-cement interface (Signore et al., 2009). The quartz fiber post will therefore act as a wedge and the energy internally in the post is transferred to the dentin causing failure (Figueiredo et al., 2015).

The interaction between the Post System and Post Diameter variables was not statistically significant, as for each system there was no great variation in the maximum fracture force when the diameter was changed. The greatest variation occurred for quartz fiber posts, however, no statistical significance was detected. Such a finding may suggest that in order to achieve the maximum possible resistance for each material, a larger diameter retainer was not necessary, which would lead to a reduction in the mineral structure of the canal's internal wall, causing a weakening of the tooth root (Marchi et al., 2008).

This study is not intended to generate recommendations on which is the best intraradicular retainer. The main contribution of our findings is to guide that the amount of dental wear alone is not a major factor for the indication of the retainer.

Each clinical situation requires an accurate study so that the diagnosis, planning and predictability of restorative objectives are achieved. In this way, the results of this test may suggest the possibility that posts with smaller diameters reach fracture resistance similar to posts with larger diameters. This observation reinforces the importance of preserving root dental structure. However, further confirmation of these results is still necessary, especially with longitudinal clinical studies that can evaluate the influence of the variation of factors such as the diameter and the mechanical properties of the prefabricated posts, in the maximum resistance to fracture of teeth with great structural losses.

In addition, some limitations of the present in vitro study suggest that its results should be considered with caution. The absence of mechanical or thermomechanical cycling limited the comparability with the oral environment. Further studies are needed to seek to confirm the findings of this study when other possible covariables related to the oral environment and/or habits related to patients can be studied.

5. Conclusion

In conclusion, a larger diameter only gives greater resistance to fracture for quartz fiber posts. Carbon fiber posts have fracture resistance similar to glass fiber and quartz fiber posts, regardless of diameter. For large diameter, the post type used does not differ in fracture resistance. Regardless of the diameter, the clinical condition without post cementation provides the highest fracture resistance.

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