Evaluation of the strength of glass fiber-reinforced composite posts placed in root canals in different quantitative configurations and exposed to crushing forces

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Abstract: The strength of fiber glass reinforced composite (FRC) posts, inserted in root canals in different quantitative configurations and exposed to crushing forces, assuming no adhesive connection in the coronal area, was evaluated. Three systems of FRC posts and one core build-up material were used in this study. The test was performed on FRC posts in three different quantitative configurations. The posts were cemented in the root canals in 36 premolars. 21 teeth were exposed to vertical forces, while 15 teeth were exposed to forces at an angle of 45° with respect to the vertical axis. After the strength tests, each sample was analyzed in the micro computed tomography (micro-CT) in order to verify that the forces do not cause defects in the areas of the adhesive connection. The largest values of the crushing forces (over 1000 N), which caused the destruction of posts were observed in case of Ena Post used in the form of single post with the greatest diameter or composed of three posts with different diameter, as well as for triple Postec Plus posts. In the case of the force acting at the angle of 45° no statistically significant differences were observed for all post configurations. No defects were found in micro-CT images of the analyzed areas of adhesive connections. The obtained results do not confirm the concept that the use of more than one post per canal may significantly improve the clinical effectiveness of FRC posts – the differences in the values of the destructive force per one post and multiple posts were not statistically significant.

Keywords: fiber-reinforced composite posts, crushing strength, micro computed tomography.

Wytrzymałość na zgniatanie wkładów kompozytowych wzmocnionych włóknem szklanym umieszczonych w kanałach korzeniowych w różnej konfiguracji ilościowej

Streszczenie: Badano wytrzymałość na zgniatanie wkładów kompozytowych zawierających włókno szklane (FRC) umieszczonych w kanałach korzeniowych w różnych konfiguracjach ilościowych, przy założeniu braku połączenia adhezyjnego w obszarze koronowym. Ocenie poddano trzy systemy wkładów FRC oraz polimerowy materiał typu *core build-up*. Wkłady w trzech różnych wariantach ilościowych zacementowano w kanałach 36 zębów przedtrzonowych. 21 zębów poddano działaniu siły zgniatającej w kierunku pionowym, a 15 – działaniu siły pod kątem 45° w stosunku do osi pionowej. Po przeprowadzeniu testów wytrzymałościowych każdą próbkę analizowano za pomocą mikrotomografu komputerowego w celu sprawdzenia, czy połączenie adhezyjne w kanale korzeniowym zostało zerwane. Największe wartości (powyżej 1000 N) użytej siły zgniatającej, powodującej zniszczenie wkładów, odnosiły się do Ena Post stosowanego w postaci pojedynczego wkładu o największej średnicy lub złożonego z trzech o różnej średnicy oraz do Postec Plus w postaci wkładu potrójnego. W wypadku działania siły zgniatającej pod kątem 45° w stosunku do osi pionowej nie stwierdzono różnic statystycznie istotnych między wartościami średnimi tej siły w odniesieniu do wszystkich konfiguracji wkładów. Na podstawie obrazów uzyskanych w mikroobrazowej tomografii komputerowej (micro-CT) nie stwierdzono zerwania lub uszkodzenia połączenia adhezyjnego w analizowanych obszarach. Uzyskane wyniki świadczą, że zastosowanie w kanale korzeniowym więcej niż jednego kompozytowego wkładu zawierającego włókna szklane nie zwiększa w istotnym stopniu efektywności wypełnienia; różnice

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w wartościach siły niszczącej pojedynczy wkład i wkład wielokrotny nie były istotne statystycznie.

Słowa kluczowe: wkłady polimerowe wzmocnione włóknem szklanym, wytrzymałość na zgniatanie, mikroobrazowa tomografia komputerowa.

The final effect of the procedure for post-endodontic restoration of teeth is often difficult to foresee. Optimal – in terms of aesthetics and functionality – restoration of lost hard tissues is challenging in many cases. If more than 50 % of the coronal part of a tooth is lost, the use of posts is recommended for stabilizing the restoration [1]. In the last decades, various metal alloys were used for such posts. However, their usage raises a number of concerns, as they do not ensure the aesthetics (due to metallic color and lack of translucency) and they may contribute to root cracks [2, 3]. In the 1990s, pre-shaped glass fiber-reinforced composite posts (FRC posts) were introduced, which are now much more common than metal posts [2, 4]. Their use is mainly motivated by the fact that their value of the elasticity module is similar to that of dentin (which allows for restoration of the natural distribution of functional stresses in the mineralized tooth tissues and reduction of the root crack risk), as well as by their good adhesive and aesthetical properties [4–6].

However, the conducted clinical studies indicate that the use of single FRC posts for the stabilization of post-endodontic tooth restoration is not 100 % efficient method [7, 8]. We have found cases of failures, which most often stem from the weakness or rupture of the adhesive connection. In such situations, the post is typically damaged without adversely affecting the root structure. However, it is not always possible to select the optimum size of a post for the spaces in the canal [9]. This especially refers to the canals, which after being processed, do not have a circular cross-section (the change in their shape into circle causes excessive loss of healthy tissues, which leads to weakening of the root structure), which are too wide so that they exceed the size of available posts and exhibit considerable differences in the diameter of the coronal and apical part [10]. In such situations, the use of individually shaped posts or the use of more than one post per canal is proposed [11, 12]. Then, an individual restoration consisting of posts with different configurations is formed. Therefore, we can use several posts with the diameter ≤ 1 mm (Fig. 1a), place the post with the maximum diameter centrally and fill the remaining space with ≤ 1 mm wide posts (Fig. 1b) or use two posts with the same or different diameter (Fig. 1c).

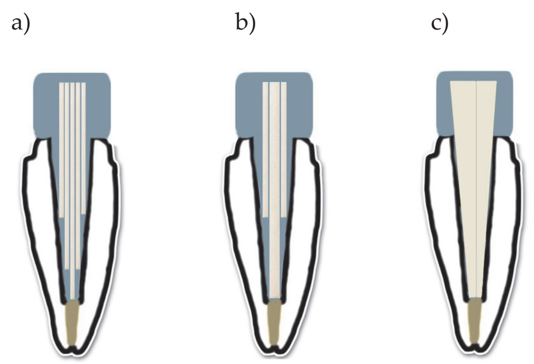

Fig. 1. Exemplary configurations of FRC posts in a root canal: a) several posts with the diameter ≤ 1 mm, b) placement of the post with the maximum diameter centrally and filled the remaining space with ≤ 1 mm wide posts, c) use of two posts with the same or different diameter

The adhesive connection between posts and the canal dentin is ensured by polymer cementing materials [13, 14]. The method allows for maximum preservation of healthy root dentin, restricts the possibility of the occurrence of empty spaces and requires the use of lower amount of polymers, which has a positive influence on the reduction of stresses occurring during polymerization [15].

The available literature does not offer reports describing the failures after the use of multiple posts in a single root canal. However, due to the possibility of severe articular overloads, adhesive rupture may take place between the polymer restoration and the canal dentin or between the posts.

The aim of the study was to assess the strength of composite posts reinforced with glass fiber, inserted in root canals in three different quantitative configurations, subjected to vertical crushing forces and crushing forces acting at an angle of 45° with respect to the vertical axis, under the assumption that there was no adhesive connection in the coronal area.

EXPERIMENTAL PART

Materials

The following materials were used in the study:

– Fiber-reinforced composite posts:

Postec Plus (Ivoclar Vivadent) – ethoxylated bisphenol A dimethacrylate, Bis-GMA (bisphenol A diglycidyl ether dimethacrylate), 1,4-butanediol dimethacrylate, tetramethylene dimethacrylate, ytterbium trifluoride, glass fibers, catalysts and stabilizers, taper FRC posts in diameter 1.3–0.6 mm [size 0] and 2.0–1.0 mm [size 3].

Ena Post (Micerium) – Bis-GMA, UDMA (urethane dimethacrylate), 1,4-butanediol dimethacrylate, tetramethylene dimethacrylate, glass fibers, taper FRC posts in diameter 1.25–0.8 mm [white mark (W)], 1.45–1.0 mm [yellow mark (Y)], 1.65–1.2 mm [blue mark (B)], and 1.88–1.4 mm [black mark (Bc)].

Fiber Post (GC) – 1,6-hexanediyl bismethacrylate, dibenzoyl peroxide, (1-methylethylidene)-bis[4,1-phenyleneoxy(2-hydroxy-3,1-propanediyl)] bismethacrylate, and glass fiber, parallel FRC posts tapered only at the end in diameter 1.0 mm, 1.2 mm, 1.4 mm and 1.6 mm.

– Silane coupling agent [Ceramic Primer (GC)] – tetrakis(trimethylsilyl)silane, methyl methacrylate, 7,7,9--(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 2-hydroxyethyl methacrylate, ethyl alcohol.

– Core build-up composite material – Gradia Core (GC):

Gradia Core base – 7,7,9-(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 2,2'-ethylenedioxydiethyl dimethacrylate, 2,2-dimethyl-1,3-propanediyl bismethacrylate, iron(III) oxide, fluoroaluminosilicate glass filler;

Gradia Core catalyst – 7,7,9-(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 2-hydroxy-1,3-dimethacryloxypropane, dibenzoyl peroxide, 2,6-di-*tert*-butyl-*p*-cresol;

Gradia Core self-etching bond (A) – 2,2'-ethylenedioxydiethyl dimethacrylate, 7,7,9-(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, 2-hydroxy-1,3-dimethacryloxypropane, ethyl alcohol;

Gradia Core self-etching bond (B) – 2,2'-[(4-methylphenyl)imino]bisethanol, ethyl alcohol.

– 5.25 % sodium hypochlorite solution [CHLORAXID (Cerkamed)].

– Villacryl SP (Zhermapol) (self-curing polymer) – liquid (methacrylic resin, dimethacrylate ethylene glycol, *N*,*N*-dimethyl-*p*-toluidine) and powder [poly(methyl methacrylate), dibenzoyl peroxide and pigments].

Sample preparation

The canals of previously extracted 36 single-rooted premolars were prepared using Gates-Glidden drills (No. 3, 4, 5 and 6) and parallel shank twist drill, long series, type N, DIN 340, HSS, code VN20010, diameter 2.4 mm (ZPS-FRÉZOVACÍ NÁSTROJE a.s.). Next, the crowns of the teeth were leveled to the height of the cervix. Upon preparation, the teeth were placed in special containers filled with non-polymerized acrylic Villacryl SP. 21 teeth were installed vertically and 15 at the angle of 45 degrees (3 samples for each examined configuration of FRC posts). Twenty-four hours after the polymerization of the acrylic, all the canals were prepared for adhesive bonding according to the indications of the GC Gradia Core material. The post space was chemically cleaned with 5.25 % NaOCl, rinsed with water, dried using an air stream and paper points, and the canal dentin was coated with bonding material Gradia Core self-etching bond (GC). After 30 seconds any excess of the bonding material was removed using paper points and the material was dried thoroughly for 10 seconds with oil-free air until the adhesive film no longer moved. The bonding agent was cured using a visible light curing unit Astralis 7 (Ivoclar/Vivadent) for 10 seconds. Subsequently, the core build-up material was placed inside the canals by means of a special mixing--application tips. Before cementing, the posts were covered with silane coupling agent that was dispersed with a weak stream of air and then coated with a thin layer of cementing material. Each post was placed in a canal with its crown part protruding ≈ 10 mm above the surface of the tooth (Table 1).

T a b l e 1. Configurations and types of FRC posts

Configuration of the posts	Post	Code	Mark/size/ diameter and number
1 post	Ena Post GC Post Postec Plus	EP1 GC1 PP1	Bc 1.6 mm size 3
3 posts	Ena Post GC Post Postec Plus	EP3 GC3 PP3	B and 2 x Y 1.0, 1.2, 1.4 3 x size 0
4 posts	Ena Post	EP4	4 x W

Finally, GC was cured by exposing to light for 20 seconds from the labial and lingual sides of the tooth using a halogen polymerization lamp [Astralis 7 (Ivoclar/Vivadent)].

Methods of testing

All samples were exposed to crushing forces in an Instron 4411 device (Instron, 825 University Ave, Norwood, MA, U.S.) (Fig. 2). The samples were stressed in accordance with ISO 4049 standards (pressure of 50 ± 16 N) until the post was crushed.

After the strength tests, each sample was analyzed in the micro-CT (SkyScan 1172, Bruker micro-CT, Kartuizersweg 3B, 2550, Kontich, Belgium) in order to verify that the forces do not cause defects in the post-cement-dentin interface.

All statistical analyses were performed using the STATISTICA (version 10.0) software package (StatSoft, Inc., Tulsa, OK, U.S.). The level of significance of α = 0.05 was assumed in the statistical hypothesis testing process.

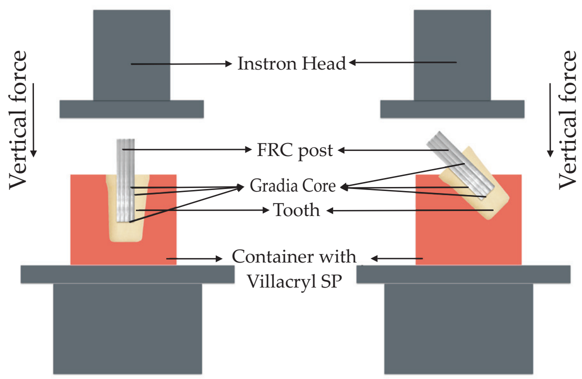

Fig. 2. Representative diagram of the evaluation of samples using the Instron device

T a b l e 2. Range of values of crushing force which caused damage of the post, and deflection of the post prior to being damaged

Code	*n*	Minimum		Maximum		Mean		Standard deviation	
		VF, N	VD, mm	VF, N	VD, mm	VF, N	VD, mm	VF, N	VD, mm
EP1	3	1054	0.66	1660	1.29	1311.67	1.023	313.01	0.326
GC1	3	903.1	0.84	1146	1.96	995.7	1.583	131.33	0.664
PP1	3	720	0.48	1284	1.74	953.83	1.287	294.08	0.7
EP3	3	1173	1.43	1668	2.89	1401.33	2.03	249.72	0.764
GC3	3	520	1.67	717.06	4.26	589.23	3.233	111.28	1.376
PP3	3	808	0.49	1593	1.17	1216.33	0.857	393.46	0.343
EP4	3	759	1.31	1266	1.95	976.17	1.65	251.19	0.322

VF – vertical force, VD – vertical deflection, *n* – number of samples.

T a b l e 3. Range of values of crushing force acting at the angle of 45 degrees with respect to the vertical axis, which caused damage of the post, and deflection of the post prior to being damaged

Code	*n*	Minimum		Maximum		Mean		Standard deviation	
		VF, N	VD, mm	VF, N	VD, mm	VF, N	VD, mm	VF, N	VD, mm
EP1	3	176	2.39	347.1	2.79	243.37	2.567	91.16	0.204
GC1	3	155.4	1.75	292.4	2.83	205.47	2.163	75.58	0.583
EP3	3	229	2.85	378	3.55	292.73	3.157	76.8	0.358
GC3	3	168.1	2.96	240	6.96	210.43	5.6	37.61	2.287
EP4	3	177.9	1.54	277.6	3.41	237.17	2.517	52.45	0.938

VF – vertical force, VD – vertical deflection, *n* – number of samples.

RESULTS AND DISCUSSION

The values of crushing force which caused the damage of the post, and deflection of the post prior to being damaged are presented in Tables 2 and 3.

The micro-CT images showed that there was no failure of the adhesive bond between the core build-up material and the post and/or dentin (Fig. 3). In some images, air bubbles were observed, enclosed in the structure of the polymerized cement. These bubbles appeared alone, in different places, and had different sizes, ranging from weakly visible to clearly visible.

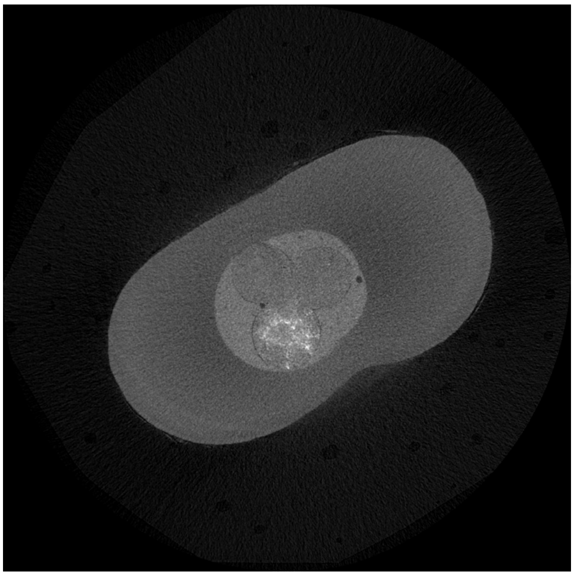

Fig. 3. Exemplary micro-CT image of posts in root canal area

Statistical analysis

For each group of samples, minimum and maximum values were specified and the mean value and standard deviation were calculated. In all cases, the posts were crushed or sheared (Fig. 4).

In the statistical analysis of the obtained results, the value of the force acting on the post and the maximum deflection of the system before failure were taken into consideration.

In the analysis of the mean values, the univariate variance analysis was used. The homogeneity of variance was tested using the Brown-Forsythe test. The NIR test was used in the role of post-hoc multiple test.

The application of prefabricated or custom-made glass fiber-reinforced composite posts for the restoration of endodontically treated teeth is a method known for many years [9, 16]. Clinical studies have reported success rates in above 95 % for teeth restored using this method [7, 8, 17]. In order to enhance the application of FRC posts, the use of more than one post per canal has been proposed [18, 19]. That concept assumes the individual restoration using multiple FRC posts inserted in different configurations. However, contrary to the case of a single post, the cement used for the cementing multiple FRC posts must fill spaces of different dimensions, which may influence its durability when it is exposed to occlu-

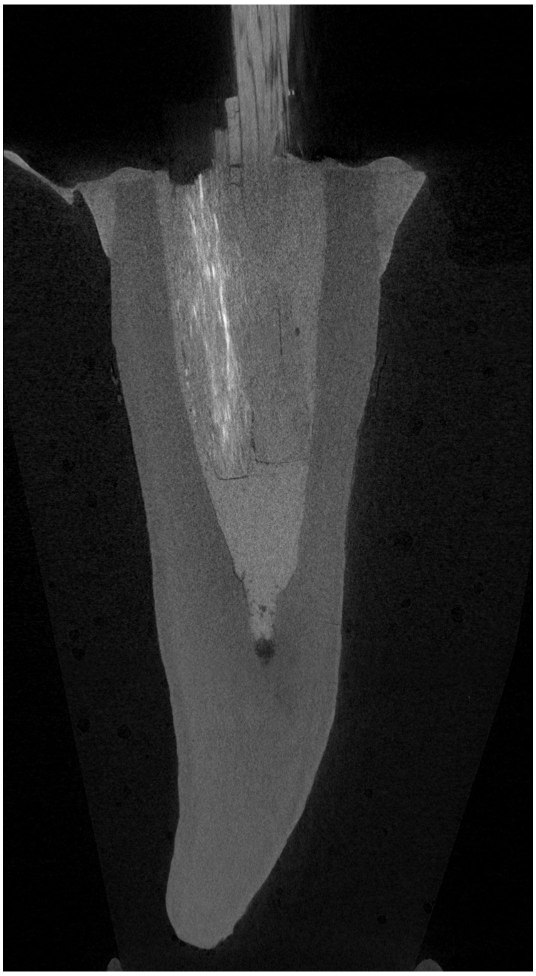

Fig. 4. A damaged post

sal forces. Because of that, the use of core build-up polymer appears to be a good solution for the cementing of different configurations of FRC posts [14]. Retentive force of glass-fiber posts inserted with core build-up materials has been assessed only in a few studies [20, 21].

The present study determined the strength of FRC posts inserted in root canals in three different quantitative configurations, cemented using the core build-up polymer, exposed to crushing forces, under the assumption of the lack of adhesive connection in the coronal zone.

The highest values of crushing forces (over 1000 N) causing destruction of the posts were observed in the case of Ena Post used in the form of one post with the greatest diameter (EP1) and three posts with different diameter (EP3), and three Postec Plus posts (PP3). A slightly lower force was necessary for the destruction of the remaining configurations of posts, except of three GC posts of different diameters. On the basis of the conducted statistical analysis, statistically significant differences between GC3 and the remaining post configurations were observed. The analysis of deflection demonstrated that in the case of GC3 posts it attained the greatest values prior to the destruction and it was statistically significant in comparison to the remaining post configurations with the exception for EP3. In the case of the force acting at the angle of 45° no statistically significant differences were observed between the mean values of all post configurations. However, when analyzing the deflection, it was determined that in the case of GC3 posts it attained the highest value prior to the destruction and it was statistically significant in comparison to the remaining post configurations.

The observed deflection of the glass fiber-reinforced posts until their breaking point indicates some flexibility of posts, which is consistent with the declarations of the producer: their mechanical and physical properties are similar to those of the dentin.

In the present study, regardless of the value and direction of the force applied, no post debonding occurred.

The results obtained in the present study cannot be compared with other findings due to the differences in the empirical model and the application of glass fiber-reinforced posts in different configuration.

CONCLUSIONS

The obtained results do not confirm the concept that the use of more than one post per canal may significantly improve the effectiveness of FRC posts – differences in the values of the destructive force per one post and multiple posts were not statistically significant.

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