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ORIGINAL ARTICLE

Push-out bond strength of circular and oval-shaped fiber posts

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Abstract This study aimed at evaluating the post-root dentin push-out bond strength of circular and oval posts luted in oval-shaped canals with two different resin cements. Twenty extracted premolars with oval-shaped canals were selected, endodontically instrumented and obturated. The teeth were divided into two groups according to the drill used for post-space preparation and to the post shape (Ellipson oval tip + post and MTwoPF + DT Light-Post). Each group was then subdivided into two subgroups according to the cement (Gradia Core and Corecem Automix). The post-dentin bond strength was evaluated with the thin-slice push-out test. The bonded surface area was calculated for each post shape with an appropriate geometric formula in order to express the retentive strength in megapascal. Push-out strength data were analyzed with the Kruskal–Wallis ANOVA. The results showed that neither the drill-post system nor the cement significantly affected the push-out strength. The means (SD) of the push-out bond strengths in the experimental subgroups were the following: 11.79 MPa (4.77) for Gradia Core/Ellipson tip and post, 13.36 MPa (5.16) for Gradia Core/MtwoPF and DT Light-Post, 11.18 MPa (2.58) for Corecem Automix/Ellipson tip and post, and 10.91 MPa (3.89) for Corecem Automix/MtwoPF and DT Light-Post. In conclusion, circular and oval posts achieved similar retentive strengths in oval canals.

Keywords Push-out test · Bond strength · Oval-shaped canals · Fiber post shape

Introduction

The restoration of severely compromised teeth is often performed by using intracanal posts [1]. The main reasons hampering the clinical long-term success of post-retained restorations are loss of retention [2, 3] and root fracture [4]. Post retention can be improved by an adhesive luting technique, involving the use of dentin adhesives and resin-based luting agents [5, 6], whose reliability was reported to be material specific [6]. Root fractures can be minimized by using fiber posts [7, 8], which have a modulus of elasticity similar to dentin and subsequently, allow for a more uniform distribution of loads along root dentin compared to metal posts [9]. Currently, the restoration of non-vital teeth by means of composite resin combined with fiber posts represents a highly reliable treatment option [10].

The adhesion to root dentin has always represented a challenge for dental clinicians because of the unfavorable ovoid canal configuration [10, 11]. Several factors affecting the post-root dentin strength were evaluated, such as the pretreatment of root dentin [12, 13], the influence of different root canal regions [14, 15], the type of resin cement and adhesive [16, 17], the adhesive application modes [18], the translucency of the fiber post [18–20], the filler content of the cement [21, 22], the cement thickness [23–25] and the fiber post surface treatments [26, 27]. To date, no studies evaluated the influence of the fiber post shape on the post-root dentin strength.

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As root canals can have different shapes [28], the resin cement thickness around the post can also vary [29]. In fact, the shape of the post influences the amount of resin cement if there is a discrepancy between the post's and the canal's shapes. In oval-shaped canals, the use of oval posts correlated with the decrease of resin cement thickness around the post [29] represents a reliable clinical choice [30]. Many laboratory studies investigated the influence of different resin cement thicknesses on the bond strength of fiber posts [23–25], but there is no consensus in the literature on the ideal thickness of resin cement to improve post retention. Push-out studies showed that the cement thickness did not significantly affect the bond strength of the fiber posts to the root dentin [23, 24]. Nevertheless, a negative correlation between the thickness of the cement layer and the post-root dentin strength was also reported [4].

The aim of this laboratory study was to evaluate the post-root dentin push-out strength of circular and oval posts luted in oval-shaped canals with two different resin cements. The null hypothesis tested is that neither the post shape nor the luting material affects the push-out bond strength.

Materials and methods

Extracted human single-rooted premolars, stored in 37°C saline solution (0.9% sodium chloride in water) for less than 1 month, were cut at the cement–enamel junction using a low-speed diamond saw (Isomet, Buehler, Lake Bluff, NY, USA) to visualize the canal morphology. Mesiodistal and buccolingual radiographs of each tooth were performed. The teeth with the ratio between the long and short canal diameter at 5 mm from the apex ≥2 could be assumed to have an oval-shaped canal [31].

Twenty teeth with oval-shaped canals were selected and endodontically treated. After the coronal access, a K-file #10 (Dentsply Maillefer, Ballaigues, Switzerland) was placed into the canals until it was visible at the apical foramen. The working length was set 1 mm shorter than this length. The canals were instrumented with NiTi rotary instruments (MTwo files, VDW, Munich, Germany) mounted in a 16:1 gear reduction handpiece (Tecnika Vision, ATRsrl, Pistoia, Italy), while irrigating with 5.25% NaOCl (Niclor 5, Dentale-Ogna, Milan, Italy), and finally dried with paper points (Mynol; Curaden Healthcare, Saronno, Varese, Italy). Each set of MTwo files was used for ten teeth.

The teeth were obturated with the lateral gutta-percha condensation: the master cone (medium cone; Mynol; Curaden Healthcare) was covered with a sealer (CRCS, Coltène/Whaledent Inc., Cuyahoga Falls, OH, USA) and placed into the canal. Additional gutta-percha cones (fine points; Dentsply deTrey GmbH, Konstanz, Germany) were added and compacted using a spreader (#25NT SE Root Canal Spreader; Hu-Friedy, Chicago, IL, USA) until complete canal filling. The coronal portion of the cones were removed with a warm plugger. Each treatment was checked radiographically. The teeth were coronally sealed with glass-ionomer cement (GC Fuji II, GC Corp., Tokyo, Japan) and stored in saline solution for 24 h at 37°C. The teeth were randomly divided into two groups (n=10) according to the drill-fiber post system used:

1. a fine-grit (46 µm) diamond-coated ultrasonic tip with oval section (Ellipson tip, RTD/Satelec, Merignac, France) mounted on a Suprasson handpiece at medium power for post space preparation together with oval fiber posts (Ellipson posts, RTD/Satelec), and
2. an MTwoPF drill (MTwoPF, VDW, Munich, Germany) for post space preparation together with circular posts (DT Light-Post, RTD, St. Egreve, France).

After storage, 9-mm post spaces were prepared. The tips/drills for the post space preparation were used for 1 min to remove the filling while rinsing with 10 ml of 17% EDTA solution using an endodontic needle [12]. The post space morphology was checked radiographically. Each drill/tip was used for five specimens. The posts were sandblasted with 110 µm-aluminum oxide particles (Rocatec-Pre, 3M ESPE, St. Paul, MN, USA) for 5 s at 2.8 bar (0.28 MPa) from a distance of 1 cm, cleaned with 90% ethanol and dried.

Luting procedure of fiber posts

The post spaces were rinsed with multiple rinses of de-ionized water under a stereomicroscope until they appeared completely free of debris or residual filling material. After rinsing they were dried with paper points.

The tested luting procedure involved the use of an experimental self-etching bonding agent (Gradia Core adhesive liquid A and B, GC Corp.) and the use of two different resin cements:

1. an experimental dual-cured composite resin cement (Gradia Core, GC Corporation, Tokyo, Japan) for both post cementation and core build ups, and
2. a dual cure flowable hybrid composite resin cement (Corecem Automix, RTD, St. Egreve, France) for both post cementation and core build ups.

Therefore, the two experimental groups were subdivided into two subgroups (n=5), according to the cement used.

As recommended by the manufacturer's instructions, one drop of liquid A and one drop of liquid B of the self-etching bonding agent were mixed together for 5 s with a microbrush and then applied onto the post-space walls, gently air-dried and light-cured for 10 s. Both resin cements were placed into the post space using an intraoral tip to fill the root canal, then the post was inserted and the cement was light-cured for 40 s. The core build up was made up with the same material used for the cementation and light-cured for 20 s. The specimens were stored in saline solution for 24 h at 37°C. Afterwards each specimen was sectioned perpendicularly to the long axis of the root into five to six 1-mm thick slices using a low-speed diamond saw (Isomet, Buehler) under water cooling, resulting in 25 to 30 slices per experimental group.

Bond strength evaluation

In order to evaluate the bond strength a *thin slice push-out strength test* was performed [32]. A cylindrical plunger was mounted on a universal testing machine (Triax 50, Controls SPA, Milan, Italy) and positioned on the apical aspect of each root slice. This ensured that each inverted, truncated fiber post section could be dislodged in an apical–coronal direction. A load was then applied to the post surface that resulted in shear stresses along the luted interfaces. Loading was performed at a crosshead speed of 0.5 mm per minute until failure. The latter was manifested by the extrusion of the post segment from the root slice.

The retentive strength of the post segment was expressed in megapascals, by dividing the load at failure in Newtons by the interfacial area (A) of the post fragment, which corresponds to the bonded area, in square millimeter. The latter was calculated differently according to the shape of the tested posts. When testing circular posts, the circular post slices were considered as truncated cones; therefore, the interfacial area was calculated as the lateral surface of a truncated cone using the following formula: $A = \pi(R + r)\left[h^2 + (R - r)^2\right]^{0.5}$, where π=3.14, R=coronal post radius, r=apical post radius, and h=root slice thickness (Fig. 1.a) [32]. When testing the oval posts, the formula traditionally applied to calculate the lateral surface of the post fragments for expressing the push-out bond strength in megapascals was modified as the oval post slice could not be considered as a truncated cone with a circular base. The oval post presents a section made up of a rectangle and two equal circular segments (Fig. 1.b). Therefore, a fragment of an oval post was considered as a geometric solid figure made up of a truncated rectangular based pyramid (thicker lines) and two equal parts of a truncated cone (Fig. 1.c). The lateral surface of this geometric solid was mathematically calculated as the addition of the lateral surfaces of both the solid figures, starting from the measurement of the following parameters: the long (CE, CE‘) and short (AB, AB‘) axis of the oval post section on both root slice sides, the major rectangle axis (HD, HD’) on both root slice sides and the slice thickness (Fig. 1). The interfacial area of the post fragment was therefore calculated applying the following formula:

$$A = \left\{(\mathrm{HC}/2 + \mathrm{HB}^2/2\mathrm{HC})2\arccos\left[(\mathrm{HC}/2 + \mathrm{HB}^2/2\mathrm{HC})\mathrm{OH}\right] + (\mathrm{HC}'/2 + \mathrm{HB}'2/2\mathrm{HC}')2\arccos[(\mathrm{HC}'/2 + \mathrm{HB}'2/2\mathrm{HC}')\mathrm{OH}']\right\} \sqrt{\left\{\left[(\mathrm{HC}/2 + \mathrm{HB}^2/2\mathrm{HC}) - (\mathrm{HC}'/2 + \mathrm{HB}'2/2\mathrm{HC}')\right]^2 + \mathrm{h}^2\right\}} + (\mathrm{HD} + \mathrm{HD}')\sqrt{\left\{[(\mathrm{AB} - \mathrm{AB}')/2]^2 + \mathrm{h}^2\right\}}$$

All the measurements were made using a digital caliper with a 0.01-mm accuracy. The symbol (’) indicates the equivalent segments on either side of the slice.

Having checked that the tooth of origin was not a significant factor for bond strength, the root slices coming from all the teeth within each group were pooled together and the root slice was considered as a statistical unit. As the data distribution was not normal in one group and group variances were not homogeneous, the use of a two-way analysis of variance was precluded and the Kruskal–Wallis analysis of variance on ranks had to be applied. The level of significance was set at $p<0.05$ and the calculations were handled by the SigmaStat 3.5 software (Aspire Software International, Ashburn, VA, USA).

Results

The results of push-out bond strength testing are summarized in Table 1. The statistical analysis revealed that neither the drill-post system nor the cement was a significant factor affecting the push-out strength ($p>0.05$).

Discussion

The restoration of teeth with oval-shaped canals, such as upper premolars with a circular post whose shape differs markedly from that of the canal, raised some concerns. In fact, an incomplete post-space debridement [33], an increase in resin cement thickness around the post [29]

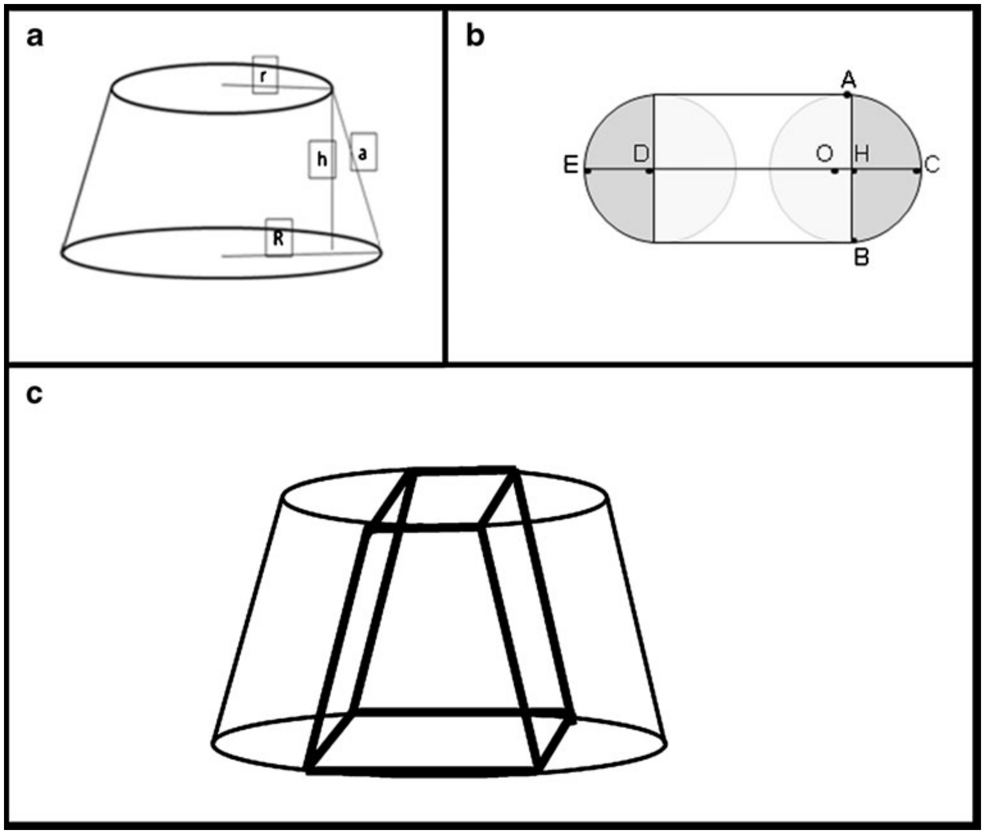

Fig. 1 **a** Schematic drawing representing a circular post slice. The interfacial area of circular posts was calculated as the lateral surface of a truncated cone. *R* coronal post radius, *r* apical post radius, *a* apothem, *h* root slice thickness. **b** Oval post section consisting of a rectangle and two equal circular segments. *CE* main axis of the oval post slice, *AB* minor axis of the oval post slice, *HD* main axis of the rectangular part, *O* geometric center of the circular part. **c** Schematic drawing representing an oval post fragment, considered as a geometric solid figure made up of a truncated rectangular based pyramid (*thicker lines*) and two equal parts of a truncated cone

and a high incidence of vertical root fractures [34], which represent the worst scenario [4] for a post retained restoration, have been reported. The vertical root fracture in upper premolars was partially correlated to the short mesiodistal diameter of the canal, which could favor stress concentration into the root, especially when an effective bond strength between the root dentin and post was not achieved [34].

A variety of experimental tests were described for the evaluation of the bond strength between root dentin and posts, such as the pull-out test, the microtensile test and the push-out test. The pulling out of the whole post from restored roots requires high loads and results in testing large adhesive interfaces, where the stress distribution is highly non-uniform [35]. The microtensile test for testing the bond strength of endodontic posts presents some difficulties due to the small size of the posts and the cylindro-conical shape of the adhesive interface. Moreover, the specimen preparation for the microtensile test resulted in high rates of premature failures [32]. The push-out test using 1-mm thick slices, as in the present study, may offer a compromise between the tests described above, featuring smaller adhesive areas compared to the extraction of complete posts, but avoiding the difficulties of the microtensile specimen preparation.

The push-out test was used in the present study to compare the bond strength between differently shaped posts and root dentin in oval-shaped canals using two different resin cements. According to the different post shapes, two distinct formulas were applied in order to determine the interfacial area for the calculation of the push-out bond strength in megapascals. The interfacial

Table 1 Descriptive statistics of push-out strengths in the subgroups

Subgroups	Mean	Standard deviation	Median	25–75%
Gradia Core/Ellipson tip and post [30]	11.79	4.77	10.4	9–15.7
Gradia Core/MtwoPF and DT Light-Post [27]	13.36	5.16	14.1	8.9–17.6
Corecem Automix/Ellipson tip and post [28]	11.18	2.58	11.4	9.4–13
Corecem Automix/MtwoPF and DT Light-Post [26]	10.91	3.89	10.1	8.1–14.2

Push-out strengths are expressed in megapascal. No significant differences were detected ($p>0.05$). The number of tested specimens is reported in square brackets area of the circular post specimens was calculated as previously reported [32], whereas a specific formula was newly introduced in the present study in order to handle the calculation of the interfacial area of the oval posts sections. The bond strengths resulted statistically comparable among all the experimental groups. The different post shapes, which correlate with different cement thicknesses [29], did not affect the results and this finding confirms the results of other push-out studies, which showed that the cement thickness around the post did not significantly affect the bond strength of fiber posts to root dentin [23, 24].

In terms of push-out bond strength, the oval tip-oval post system resulted comparable to the circular drill-post system, whose use represents the current clinical choice to restore an oval-shaped canal through a fiber post. Nevertheless, the use of the oval tip-oval system could present some advantages when restoring oval canals. In fact, the use of the fine-grit oval tip was reported to achieve a better post-space debridement than a circular tip, respecting the oval canal's shape [33]. On the contrary, Ni-Ti instrumentation tends to maintain a self-centered position while rotating with the creation of a circular bulge to fit a circular post into an oval post-space [33], thus implying the sacrifice of sound dental tissue and decreasing the root strength [36]. Moreover, the use of both oval tip and oval post was correlated to a better post fitting to oval post-spaces than that obtained with circular posts [29]. This procedure is easier and more time-saving than some chair-side techniques previously suggested for adapting the shape of the post to the canal's anatomy. The combination of a fiber post with a dual-curing resin cement in order to create an *anatomical post* [37], the lateral compaction of two or more small fiber posts to fill the post space [38] or the adaptation of a cylindrical fiber post to the canal's anatomy with a diamond-coated bur [39, 40]. Furthermore, the thickness of the resin cement may represent a critical factor in the clinical performance of fiber posts, as an excessively thick layer of resin cement around a fiber post was correlated to higher frequencies of post debonding [41, 42]. The oval tip-post system could overcome this inconvenience, as it was shown to achieve a lower cement thickness around the post compared to the circular drill-post system [29]. It might be speculated that the reduced thickness of the luting material results in a lower polymerization shrinkage and a subsequently lower polymerization stress, thus not impairing the bond strength [43].

Within the limitations of this laboratory study, it may be concluded that the push-out strengths achieved with the use of the oval tip-oval post system were comparable to those obtained using a circular drill-post system. Since neither the post shape nor the luting material affected the push-out bond strength, the tested null hypothesis was accepted.

Conflict of Interest The authors declare that they have no conflict of interest.

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