Odontology (2024) 112:158–168
https://doi.org/10.1007/s10266-023-00820-1

ORIGINAL ARTICLE

Push-out bond strength and SEM fractographical analysis of hollow fibre posts used with self-adhesive resin cement: a pilot study

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Received: 23 November 2022 / Accepted: 5 May 2023 / Published online: 12 May 2023
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Abstract

Detachment is the major cause of failure of endodontic fibre posts. Hollow posts have been recently introduced to overcome such issue. The primary aim of this pilot study was to compare the push-out bond strength of hollow posts and traditional solid posts. Eight round-shaped single-canal premolars extracted for periodontal reason were selected as sample and equally randomized into two groups: (i) traditional solid fibre posts-TECH21xop and ii) hollow fibre posts-TECHOLE. A dual-curing self-adhesive cement (new TECHCEM) was used for posts placement. Six horizontal sections—two from each portion of the root (coronal, middle and apical)—were obtained from each sample root, yielding a total of 24 sections for each group. Push-out test was performed on the sections and bond strength values were compared between groups and within each group. Scanning electron microscope (SEM) fractographical analysis was conducted on each section. Additional SEM and EDX analyses were performed on new samples of both posts, to assess fibres density and distribution, and the chemical composition of the fibres and the matrix. Hollow posts showed a significantly higher push-out bond strength (6.36 ± 1.22 MPa) than solid posts (3.64 ± 1.62 MPa). Among the three root portions of the same group, there was no significant difference in bond strength. In both groups, the most frequent type of fracture was a mixed adhesive failure with the cement covering 0 to 50% of the post perimeter. Hollow post fibres appear more similar in size and have a more homogeneous distribution, compared to solid posts. The two post types also have different chemical compositions.

Keywords Fibre hollow posts · Fibre posts · Fractographical analysis · Push-out bond strength · Self-adhesive cement

Introduction

Endodontically treated teeth show a decreased resistance to fracture of 5 to 69%, compared to sound teeth, depending on the shape and the size of the access cavity [1]. The amount of residual dental tissue and the tooth position in the oral cavity are the main factors determining the choice of the appropriate restoration. The use of endodontic retentions, such as posts, is recommended to achieve a better retention of the coronal restoration and to improve the distribution of the masticatory forces along the root. The shape, the composition and the surface characteristics of the posts are essential to ensure appropriate retention, which is defined as the resistance to displacement along the main axis of the post, and long-term success [2]. Fibre-reinforced prefabricated posts are widely used for the restoration of endodontically treated teeth, with a reported 5 year survival rate of approximately 93% [3]. Major advantages of prefabricated fibre-reinforced posts, as compared to metal posts, are related to

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high fatigue resistance and high tensile strength, an elastic modulus similar to dentin, and the possible use of adhesive cementation [4]. As a result, the forces are evenly distributed along the post-cement-dentin interface and to the remaining tooth structure, minimizing the risk of vertical root fractures [5]. With regard to shape, cylindric posts provide a higher retention, although a greater removal of dentin is required during post-space preparation, leading to an increased risk of root fractures. [6] Therefore, the most favourable post design should feature a cylindric-shaped coronal portion and a tapered shape approximately in the 4 mm apical portion that naturally fits the root canal anatomy [2]. The major cause for failure in fibre-posts is, however, detachment [7]. To avoid failures due to post detachment, an adequate adhesive bond between post, cement and dentin is required. The adhesive bond is of both chemical and micro-mechanical nature, and although several surface mechanical treatments (sandblasting) and chemical conditionings (silanization, acid etching, bonding agents) have been suggested to improve such bond, it is still a complex procedure, considerably depending on the sensitivity of the technique [8]. A number of possible factors can affect the quality of the adhesive bonding, such as the chemical incompatibility between the resin component of the cement and of the post, the persistence of root canal obturation residuals on post-space walls, the incorrect handling of the adhesive system, the decreased conversion rate of the cement and bonding agent in the deepest post-space areas, polymerization shrinkage, and the possible formation of air bubbles during the cementation phase [9]. In addition, the micromechanical retention that can be obtained in the root dentin is lower as compared to the coronal dentin, due to the differences in tubules number and arrangement [10].

To improve the bonding between the post and the dentinal surface, hollow fibre-reinforced posts have been recently introduced on the market (TECHOLE, Isasan, Rovello Porro, CO, Italy).

Recent laboratory studies reported high mechanical performances for this hollow post, in terms of flexural strength, elasticity, resistance to compression and cutting, exhibiting values similar to the highest reported in literature or even higher, as compared to the same manufacturer's traditional solid post and to other solid posts with similar composition [9, 11]. According to Lo Giudice et al., in their three-point test experimental setting, these results are applicable both to unfilled and to dual-curing resin cement-filled sample posts, with better mechanical performances for the latter, thanks to a more homogeneous distribution of the forces [9].

This endodontic post is connected to the cement dispensing tip and used directly as a carrier, in a one-step simplified cementation procedure. In addition, the cement injection through the central cylindrical canal, which extends along the whole length of the post, may limit the air bubbles formation by propelling them in coronal direction. The resulting retention system might thus be more resistant than a traditional fibre post with similar diameter.

To further investigate the possible clinical advantages in the use of this hollow-designed post, the aim of this pilot study was to compare the push-out bond strength of hollow fibre posts and of traditional fibre posts. The alternative hypothesis (H_a) tested was that the push-out bond strength values are higher in the hollow designed posts.

In addition, the differences of bond strength in relation to the different regions of the root were evaluated and compared between groups, along with the prevalence and distribution of the different types of failures. A scanning electron microscope (SEM) and Energy Dispersive X-ray (EDX) characterization of the chemical composition of the fibres and their distribution was also performed. To the best of our knowledge, this is the first study conducting such analyses and testing bond strength on hollow fibre posts.

Materials and methods

Selection of samples

A pool of extracted upper and lower premolars were stored in sterile water and 2% thymol solution (Baxter S.p.a, Rome, Italy) at 4 °C for no longer than 20 days. Only single-canal teeth with a round-shaped canal were selected (n = 10), showing no signs of root fractures, caries, resorptions, or uncomplete apex formation under 10x optical microscope inspection (OPMI Pico, Carl Zeiss Meditec Inc.). The root canal shape was considered round when the ratio between bucco-lingual and mesio-distal dimensions of the canal at 5 mm from the radiological apex, as measured on two specific radiographs, was ≤ 2.5 [12, 13].

Root canal treatment

The coronal portion of the eligible teeth was removed to obtain homogeneous sample roots of 13 ± 1 mm length. After performing an early coronal enlargement using ProTaper SX (Dentsply Maillefer, Baillagues, Switzerland), the apical patency and the working length were assessed simultaneously by inserting a 10 K-file until its tip appeared at the apical foramen under microscopic vision at 10 × (OPMI Pico, Carl Zeiss Meditec Inc.). A mechanical glide-path was obtained using PathFile n.1, 2, 3 (size 13, 16, 19 respectively and .07 taper) (Dentsply Maillefer). Root canal shaping was performed at working length with ProTaper Gold system, following manufacturer recommendations, up to the #F4 instrument (size 40, taper .06). These procedures were carried out using an X-Smart Plus (Dentsply Maillefer) endodontic motor. After each instrument, the canals were irrigated with 1 mL 5% NaOCl (Niclor, Ogna, Muggiò, Italy). Finally, a 2 min irrigation with 17% EDTA (Ogna) followed by a double-distilled sterile water rinsing (Baxter S.p.a, Roma, Italy) were performed. The root canals were dried using #F40 paper points and filled with AH Plus endodontic sealer (Dentsply Maillefer) and Thermafil Obturators #F4 (Dentsply, Tulsa Dental Specialities, Johnson City, TN, USA). The obturator handle was then removed using the ThermaCut (Dentsply, Tulsa Dental Specialities) dedicated bur, mounted on a high-speed handpiece, without irrigation. The samples were incubated at 37 °C and 100% humidity for 7 days to allow the sealer to set.

Post-space preparation

Using the PostSpace dedicated bur (Dentsply, Tulsa Dental Specialities), 7 mm of the Thermafil obturator was removed, followed by instrumentation with Gates-Glidden burs (n.1, 2, 3 and 4) to eliminate possible gutta-percha residuals adhered on the canal walls. After each bur, irrigation with 1 mL of 5% NaOCl was performed. Post-space preparation was completed using a 1.2 mm diameter calibrated bur (TECH #12 Isasan) 7 mm apical from the orifice of the root canal. A 1 mL 5% NaOCl irrigation and a 1 mL 17% EDTA 2 min irrigation were then carried out, followed by a final 3 mL saline rinsing. Root canals were dried with #F4 paper points.

Post cementation

Sample teeth were randomly divided into two groups: traditional solid fibre posts ($n = 4$) and hollow fibre posts ($n = 4$) were used in group 1 and group 2, respectively. The hollow endodontic posts used in this study (TECHOLE, Isasan) feature a cylindrical-conical shape with a rounded tip and a diameter of 1.2 mm in the cylindrical portion. According to the manufacturer, they are made of more than 60% pre-tensioned silica fibres parallel to the longitudinal axis of the post, immersed in an epoxy resin matrix. A new dual-curing self-adhesive cement (new TECHCEM, Isasan) was used to perform the post cementation.

In group 1, the cement was extruded using the dedicated endodontic needle (Endo-Tip) mounted on the self-mixing syringe, by placing the Endo-Tip at the deepest portion of the canal and moving backwards up to the orifices, keeping contact with the cement to limit or avoid possible air-bubbles formation. The traditional silica fibre post #12 TECH21xop (Isasan) was placed at 7 mm depth and gently moved up and down, to further prevent air-bubbles formation. After post placement, 60s light curing was performed using Starlight Pro (bandwidth 440–480 nm-Mectron S.p.a, Carasco, GE, Italy) at 1400 mW/cm^2 for 60s, keeping the light tip orthogonal to the post, over its coronal portion.

In group 2, the sterile pre-assembled carrier-post unit (TECHOLE, Isasan) was mounted on the cement self-mixing syringe and placed 7 mm deep in the post-space. Keeping the post in place, the cement was extruded through the carrier-post unit until it emerged from the canal. During this procedure it is recommended to apply to the post an up and down movement of 1 to 2 mm to allow the proper extrusion of the cement. Light curing was performed using Starlight Pro at 1400 mW/cm^2 for 60 s, keeping the light tip as orthogonal as possible to the post, adjacent to the carrier and over its coronal portion. Finally, the post was separated from the connector using scissors.

All the experimental procedures were carried out by the same experienced endodontist, using a 10x magnification with an optical dental operating microscope (OPMI Pico, Carl Zeiss Meditec Inc.).

Samples preparation for analysis

The samples were embedded in methyl-methacrylate resin (Technovit 3040, Heraeus Kulzer–Wehrheim–Germany). Using a rotary microtome (Leica SP 1600, Nussloch, Germany) with a 300 µm-thick blade, under continuous irrigation, starting from the top of the root canal a first 500 µm-thick section was cut and discarded, to remove the methyl-methacrylate resin covering the post coronal surface; then, 6 serial horizontal sections of 500 m thickness were cut from each sample, the most apical section obtained being at 5.3 mm depth. Based on the position of the post in the root canal, two sections were classified as coronal (n.1 and n.2), two as middle (n.3 and n.4) and two as apical (n.5 and n.6).

SEM analysis of cement fit

All transverse sections of one sample tooth from each group were observed through scanning electron microscope (SEM–Quanta 200, FEI, Eindhoven, Olanda) to verify the cement distribution on both the walls of the post and the root canal and to evaluate the presence of air bubbles. These samples were not included in further analyses.

Push-out bond strength test

The push-out test was performed by applying an axial load to the post using an instrumented nano-indenter (NHT, Anton-PaarTriTec, Peseux, Switzerland) equipped with a Ø1 mm spherical tip. The accurate positioning of the tip on the post is performed using an optical microscope with 1000X magnification lens integrated in the instrument. A growing load is applied to the post, in apical to coronal direction, at a constant loading rate of 25 N/min until debonding occurs leading to a sudden displacement of the post. The debonding load is defined as the minimum load (in newtons) under which the post is displaced from its position.

The bond strength of the post was calculated as the ratio between the load at failure and the post-dentin interfacial area (mm^2) of the specimen, using the following equation:

$$\text{Bond strength } [MPa] = \frac{\text{Debonding load } [N]}{\text{Interfacial area } \left[\text{mm}^2\right]} = \frac{\text{Debonding load } [N]}{D \times p \times H \left[\text{mm}^2\right]}$$

where D is the diameter of the post (1.2 mm), and H is the height of the section (0.5 mm).

After debonding, the displacement of the indenter tip was stopped at 180µm, aiming to avoid the complete detachment of the fractured post from its original sit, and allowing the post analyses of the whole section.

Fractographical analysis

After push-out test, each fractured section was evaluated with SEM microscope at 150x magnification to determine the types of failure. The evaluation was conducted by positioning the samples facing downward and observing the most apical surface of each section. The types of failures were classified as follows: (1) adhesive failure between post and cement (no cement on the post surface); (2) mixed failure with cement covering 0 to 50% of the post surface; (3) mixed failure with cement covering 51 to 100% of the post surface; (4) adhesive failure between cement and dentine (the cement remains adhered to the post surface); (5) cohesive failure within the dentine; (6) post fracture. Each type of failure was reported as a percentage in relation both to the total number of sections and to the number of sections within each group of coronal, middle and apical sections.

SEM and EDX analysis of the posts

The surface and a cross-sectional area of new sterile samples of each type of posts were observed through SEM, equipped with Energy Dispersive X-ray (EDX) microanalyses (INCA, Oxford Instruments, Oxford, UK). To obtain such cross-sections, the posts were embedded in a transparent epoxy resin that cures at room temperature. Samples have been moved into silicon moulds which were kept under vacuum while poring the resin, ensuring the complete filling of the central canal of the hollow post and of all the porosities of the posts. Once cured, the transversal sections were cut, and the surfaces were polished with silicon carbide (SiC) abrasive paper of progressively finer grits (400; 800; 1000; 2500) and finally lapped with a 3 µm grit diamond paste. A silver-based conductive glue was used to bond the back surface of the polished specimens to an aluminium stub, as well as to create an electrical connection between the polished surface and the aluminium stub. The polished surfaces were then metallised with a 6 nm gold film, to make them completely conductive. The cross-sections were observed in back-scattered electron mode, which provides a high contrast of the observed objects, based on their chemical composition.

The images were acquired at increasing magnifications to highlight the morphological characteristics of the posts, such as fibres size and distribution.

Statistical analysis

Values from push-out test corresponding to the two sections for each level were averaged to have one value per level per specimen. After verifying the normality of the data distribution through the Shapiro-Wilk test, push-out bond strength values were compared between the two groups using the Student's T test, whereas one-way ANOVA test was used to compare such values among the groups defined by the different root regions (coronal, middle and apical). The significance level was set at $P < 0.05$. All data were analysed using Stata/IC11.0 (StataCorp LP, College Station, Texas, USA).

Results

SEM analysis of cement fit

The sections of the solid traditional post showed an overall good fit of the cement on the outer perimeter of the post, while some voids in the cement-post interface were found, probably due the formation of air bubbles during cementation (Fig. 1a, b). The sections of the hollow post showed a very good fit of the cement to the outer perimeter and in the central hollow portion of the post, where no voids were noticed. At the outer cement-post interface only one air bubble was found (Fig. 1c, d). Being this sample considerably limited, these findings are to be considered as pilot data.

SEM and EDX analysis of the posts

SEM acquisitions of transversal sections of the posts at 150 ×, 300 × and 2000 × magnifications for group 1 and group 2 are displayed in Figure 2. Comparing the two groups at a macroscopic level, the fibres of hollow posts appeared homogeneously arranged within the matrix, and no fibre-free areas could be identified. To the contrary, large fibre-free areas can be seen in the solid post section. On the other hand, the analysis of the composite material at a more microscopic level, 2000x magnification reveals no noticeable morphological differences between the two posts—the fibres of various diameter appear well whetted by the surrounding polymeric resin, with no noticeable voids or defects. The semi-quantitative EDX chemical analyses, were performed on random points of the samples

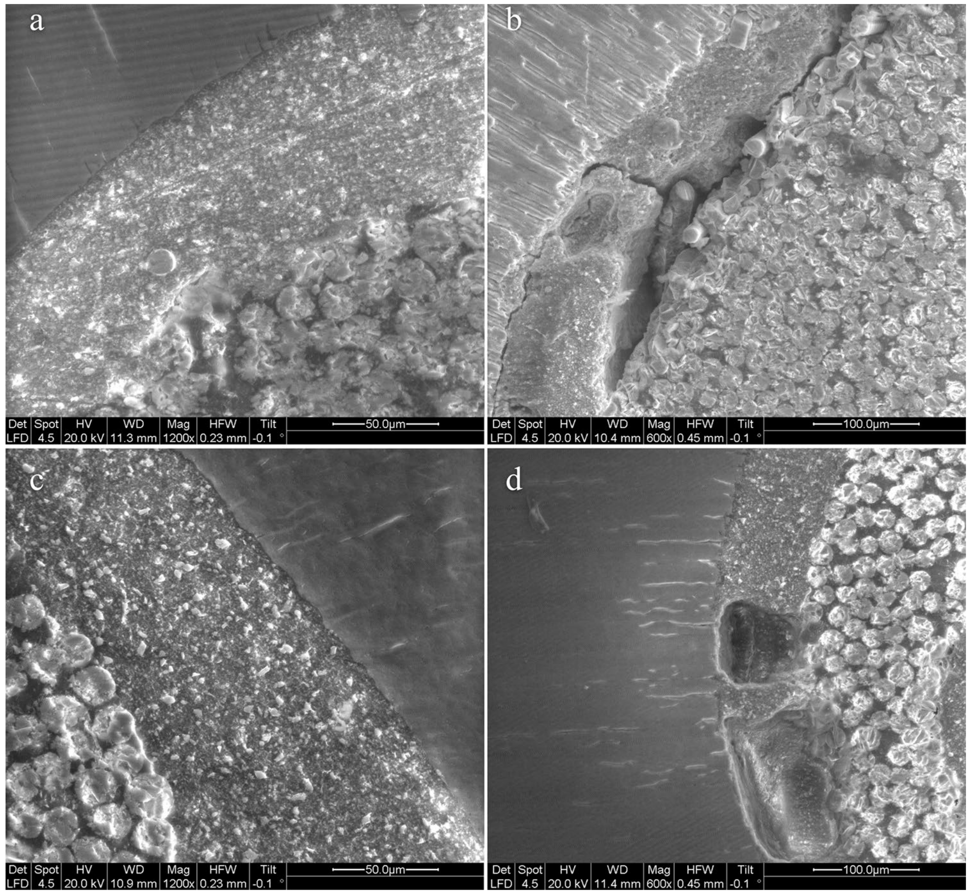


Fig. 1 SEM images of the cement adaptation on the surface of traditional solid post (**a**, **b**) and on the surface of hollow post (**c**, **d**) showing an overall good fit of the cement on the outer perimeter of the posts, while some voids at the cement-post interface are noticeable.

and the results are reported in Fig. 3. The composition of glass fibres of the hollow posts consisted of 54.5% silica (SiO_2), 20.8% calcium oxide (CaO), 12.19% aluminum oxide (Al_2O_3), and 2.33% magnesium oxide (MgO), and 0.64% sodium oxide (NA_2O). The glass fibres of the solid posts were composed of 84.8% silica (SiO_2), 8.3% sodium oxide (Na_2Oa), 6.4% calcium oxide (CaO), and 0.5% aluminum oxide (Al_2O_3) and. The comparison of SEM acquisitions of the outer surface of solid and hollow posts at magnifications 90x to 1600x showed no appreciable differences in the distribution of the fibres within the matrix (Fig. 4). The main observable difference consists in the presence homogeneously distributed fine debris well visible on the surface of solid post, while the hollow post fibres appear cleaner and well defined. The apical portion of the solid post appeared of cylindric-tapered shape, compared to the apical portion of the hollow post, which appeared almost completely cylindrical.

Push-out bond strength

From 8 sample teeth, a total of 48 root sections, 24 being from solid traditional posts (Group 1) and 24 from hollow posts (Group 2), underwent the push-out test, the results of which are reported in Table 1. Mean push-out bond strength was significantly higher for hollow fibre posts, as compared to traditional solid fibre posts (6.36 ± 1.22 MPa *vs* 3.64 ± 1.62 MPa). With regard to coronal sections, the mean value of push-out bond strength of hollow fibre posts and traditional solid posts was 6.15 ± 0.71 MPa and 3.61 ± 1.75MPa, respectively; the difference was statistically significant. As for middle sections, the mean push-bond strength was higher for hollow posts (7.17 ± 1.56 MPa), than for solid posts (3.29 ± 1.73 MPa), with a statistically significant difference. The push-out test yielded similar results for apical sections, with a higher mean value for hollow fibre posts, if compared to traditional solid posts, with no significant differences (5.76 ± 1.06 MPa *vs* 4.03 ± 1.81 MPa). Within each group, no statistically significant differences among mean values of push-out bond strength of coronal, middle and apical sections were detected.

Fractographical analysis

The distribution of different types of post failures are summarized in Table 2. The most frequent type of failure, both in

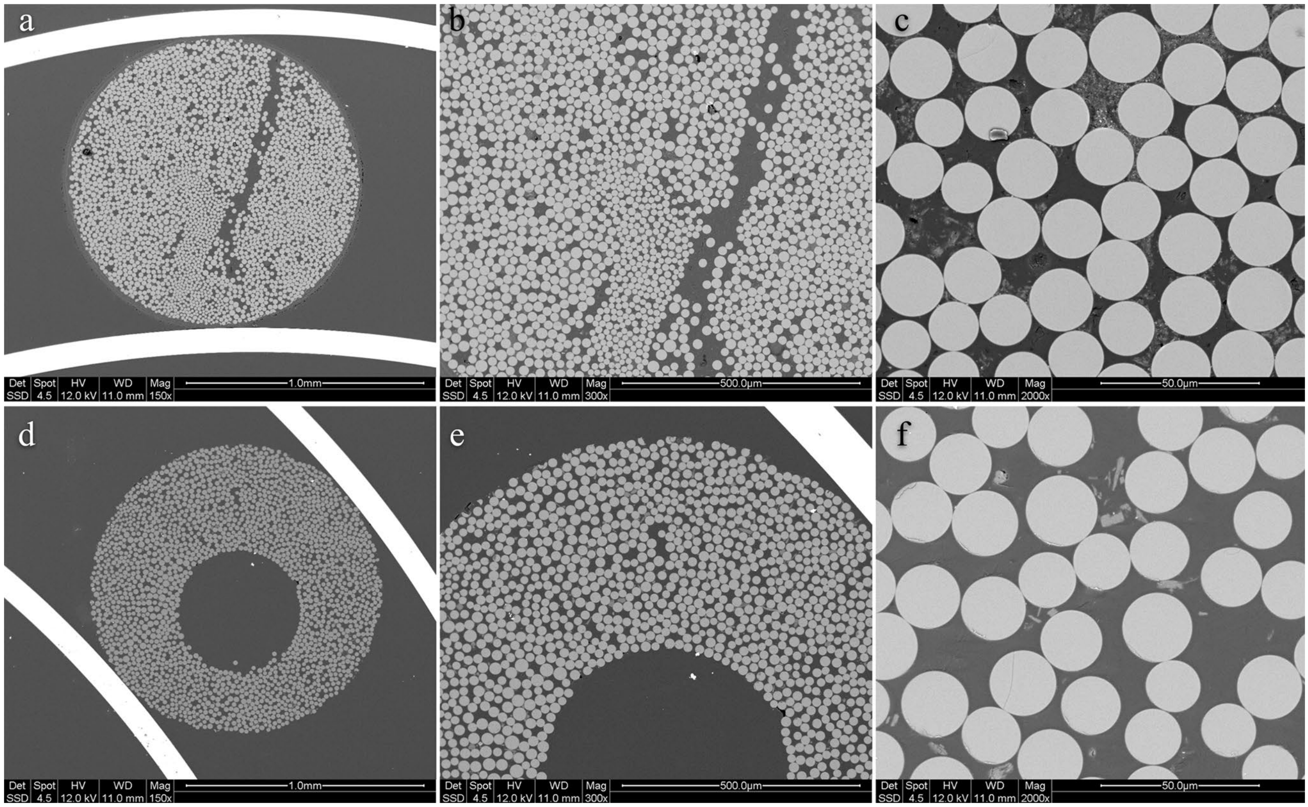
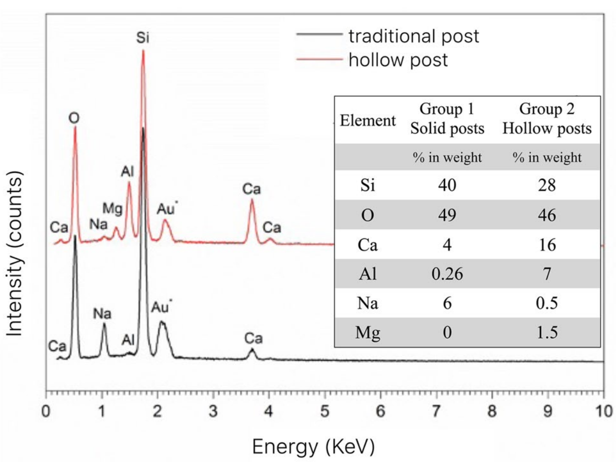


Fig. 2 SEM back-scattered acquisitions of transversal sections of new samples of solid posts (**a**, **b**, **c**) and hollow posts (**d**, **e**, **f**) at 150 ×, 300 × and 2000 × magnifications, respectively.



Element	Group 1 Solid posts	Group 2 Hollow posts
	% in weight	% in weight
Si	40	28
O	49	46
Ca	4	16
Al	0.26	7
Na	6	0.5
Mg	0	1.5

Fig. 3 Semi-quantitative analysis of the composition of glass fibres, based on stoichiometric ratios. Au detection depends on the metallization procedure.

group 1 (50%) and group 2 (41.7%) was the “mixed failure” (type N.2), with cement covering 0 to 50% of the post surface, accounting overall for the 45.8% of all failures across the two groups. SEM acquisitions of representative specimens are shown in Fig. 5. Type N.3 failure (mixed failure with cement covering 51 to 100% of the post surface) was detected in 25% of solid posts specimens and in 29.2% of hollow posts specimens, being the second most frequent failure mode. No type N.6 failures (post fracture) were recorded.

Discussion

The research has focussed on studying endodontic posts with different designs and composition, primarily to ensure long-term success and overcoming detachment as the major cause of failure [14–16]. The hypothesis that peculiar post shapes can significantly affect its retention has led to the recent introduction on the market of hollow fibre posts. Only a few laboratory studies have evaluated the mechanical performances of such posts, indicating promising results [9, 11]. In this study, we evaluated the bond strength, choosing the push-out test, since it is considered to be the most efficient and reliable assay to specifically assess the retention of the post into the root canal and along its different regions [17, 18].

Both solid and hollow posts were cemented using a dual-curing, self-adhesive cement (new TECHCEM–Isasan,

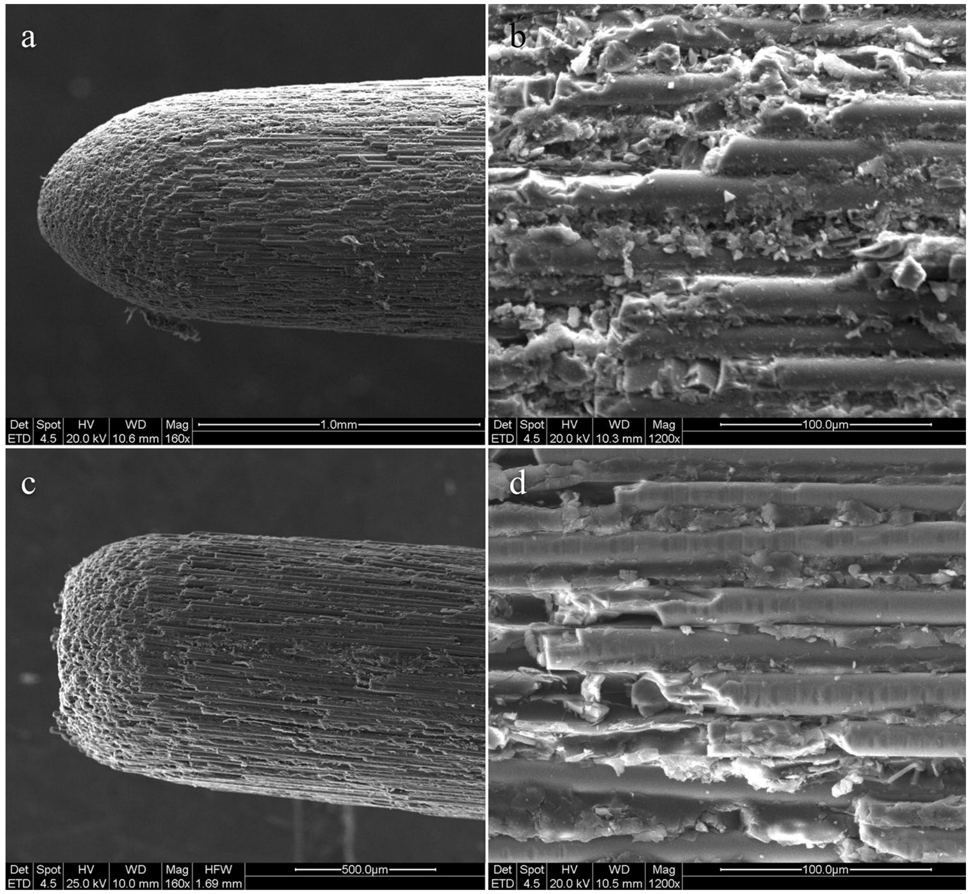


Fig. 4 SEM acquisitions of the apical portions and outer surface and of new samples of solid posts (**a**, **b**) and of hollow posts (**c**, **d**) at magnifications of 160 × and 1200 ×, respectively.

Table 1 Results of push-out bond strength test

Tooth region	Group 1 solid posts (n = 4) Mean ± SD (MPa)	Group 2 hollow posts (n = 4) Mean ± SD (MPa)	p^1
Coronal	3.61 ± 1.75	6.15 ± 0.71	*0.036
Middle	3.29 ± 1.73	7.17 ± 1.56	*0.016
Apical	4.03 ± 1.8	5.76 ± 1.06	0.150
p^2	0.837	0.255	
Total	3.64 ± 1.62	6.36 ± 1.22	*0.0001

[1]Student's *T* test

[2]One-way u ANOVA

Table 2 Results of fractographical analysis

Type of failure		Group 1 solid posts n (%)	Group 2 hollow posts n (%)	Total n (%)
N. 1	Adhesive failure (no cement on post surface)	3 (12.5%)	3 (12.5%)	6 (12.5%)
N. 2	Mixed failure (cement on 0–50% of post surface)	12 (50%)	10 (41.7%)	22 (45.8%)
N. 3	Mixed failure (cement on 51–100% of post surface)	6 (25%)	7 (29.2%)	13 (27.1%)
N. 4	Adhesive failure (detachment between cement and dentine)	3 (12.5%)	3 (12.5%)	6 (12.5%)
N. 5	Cohesive failure (detachment within the dentine)	0	1 (4.2%)	1 (2.1%)
N. 6	Post fracture	0	0	0

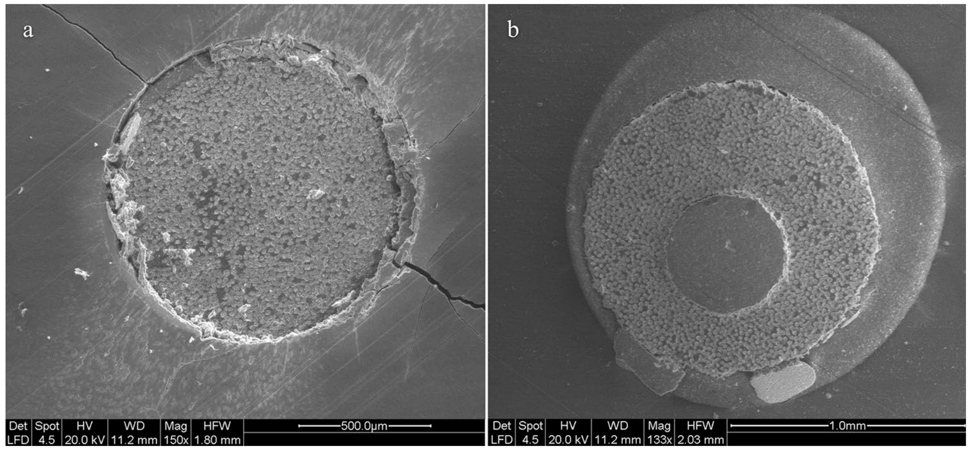


Fig. 5 SEM 150x magnified acquisitions of representative specimens for the most frequent types of failure for both groups: mixed failure (N.2) showing the cement covering 0–50% of the post surface in a solid post (**a**) and in a hollow post (**b**).

Rovello Porro, CO, Italy). The choice of a self-adhesive cement has its rationale in the fact that, rather than choosing a multi-step adhesive technique, its association with the post-cement carrier system in use allows for an extremely quick simple, and reliable cementation procedure [19–21]. Also, since the application of a bonding agent and its related light-curing step are not required, it can be expected that the use of a self-adhesive cement prevents from the risk of poorer conversion rates of the bonding agent in the deepest regions of the root canal, thus possibly providing a more homogeneous bond strength along the root canal [22, 23].

However, self-adhesive cements may show a limited dentinal infiltration since the removal of smear layer by acid etching is not required throughout the procedure [24]. To overcome such limitation, we performed a 2-minute irrigation with 1mL 17% EDTA at the end of the post-space preparation procedure, so as to gently remove the smear layer [25]. Being EDTA a mild chelating agent, it selectively removes hydroxyapatite and non-collagenic proteins, while leaving collagen unaltered, thus promoting the micromechanical retention, and increasing the bond strength along all the portions of the root canal [26].

In this pilot study, the push-out strength mean value resulted significantly higher for hollow post as compared to solid posts, therefore the alternative hypothesis was confirmed. The specific cementation technique used for hollow posts could account for these findings. In fact, the one-step procedure, and the cement injection directly through the central hollow canal of the posts possibly limit air bubbles formation and might explain the greater retention found for such posts. Conversely, the multi-step procedure required for solid posts cementation can more likely lead to the formation of air bubbles, as the cement dispensing tip is inserted first, and then removed to allow the subsequent step of post placement. Hollow posts allow for a simplified one-step procedure of cementation, where the cement flows directly through the post, then rises up along the root canal walls, thus filling any voids and propelling possible air bubbles to the surface. Moreover, these results may also be explained by the specific hollow design with resin filling, which provides a more homogeneous distribution of occlusal forces and improved structural properties, such as elasticity, flexural strength and fracture load as compared to traditional solid posts with similar composition [9].

No significant differences of mean bond strength were found within each group, among the sections belonging to different root regions. Some authors previously reported a progressive decrease of bond strength in coronal-apical direction [15, 27–29], while, similarly to our findings, other authors did not detect any significant differences of bond strength in the different root portions [30, 31]. A different configuration of the bonding interface, which can be found in the tapered shape of the root canal, has been reported to affect the stress distribution and consequently the bond strength, yielding higher compressive and tensile stresses, and tendency to displacement with increasing occlusal diameter in relation to the cervical diameter [32]. In the present study the push-out test was conducted using 0.5 mm thick sections. The reduced thickness adopted is expected to result in negligible differences between the coronal and apical surface of each section, thus ensuring an even distribution of the experimental load within each section and limiting the impact of taper on cavity configuration, and consequently on the bond strength values. In addition, other several factors may be associated to the lower bond strength found in the apical region, including the limited visibility during the apical post-space preparation, the possible persistence of root canal obturation residuals on the canal walls of the apical region, and the difficulty for curing light to reach the deepest portions of the root, thus causing a lower conversion rate of cement monomers and a weaker bond strength [29]. Also, dentinal tubules considerably decrease in number and show a different distribution in coronal-apical directions, being considered less favourable for bond strength [33, 34]. Interestingly, while Pereira et al. reported a higher bond strength in the coronal portion for conventional adhesive resin cement, using a self-adhesive cement they found a higher bond strength value in the apical portion, instead [29]. Overall, these findings may indicate that, along with the density, size and distribution of dental tubules, the properties of the cement itself can play an important role in influencing the bond strength along the root canal [29].. In fact, inorganic particle amount is higher in weight in self-adhesive cements as compared to conventional cements; this feature decreases polymerization shrinkage and improves cement stability [35]. The dual-curing polymerization mechanism of the cement used in the present study, as compared to a light-curing mechanism, is expected to ensure a more homogeneous conversion rate along all the root canal [36, 37]. On the other hand, residual stresses deriving from a short-distance light-curing can negatively affect the bonding performances of dual-curing cements [38]. In our experimental setting, one can speculate that while the light-curing occurred from a shorter distance for the coronal and middle regions, the long distance at which the light-curing occurred for the apical region possibly resulted in an unaffected local bond strength, compensating the other favourable factors associated to the more coronal regions and thus resulting in overall comparable values. Moreover, all the procedures in this study were performed at 10x magnification under dental operating microscope, which allowed to have a good control of the post-space cleaning and preparation, even in its deepest portions, thus ensuring a good and substantially homogeneous retention along all the root canal [39].

Fractographical analysis revealed that the most frequent type of failure was a mixed adhesive detachment at the post-cement interface, with cement covering 0 to 50% of the post surface (N.2), followed by a similar mixed failure, in which the post surface covered in cement amounted to 51 to 100% (N.3). Conversely, Scotti et al. reported the adhesive failure at the dentin–cement interface (N.4) as the most frequent failure mode, due to possible residuals of endodontic obturation on the canal walls, which can affect the adhesive procedures. [28] In the present study, the use of 10x magnification dental operating microscope, by contributing to the appropriate cleaning of the post-space, may have also limited the occurrence of such type of failure.

With regard to the EDX analyses, since the results obtained on the composition of the glass fibres of the posts are derived data, these values are not to be intended as absolute percentages. Nevertheless, the two observed compositions matches quite well with respectively E-glass type fibre (hollow post), and A-glass fibre (solid post) [40]. E-glass fibres possesses higher mechanical properties and better resistance to acid environments compared to A-glass fibres. To the contrary, A-glass typically possesses a higher resistance to alkaline environments [40].

Finally, the SEM analyses of the surface of two types of endodontic posts revealed that the glass fibres of the hollow post are cleaner and free of superficial particles. This may provide a more direct and homogeneous adhesion of the cement to the glass fibres, thus positively affecting the bond strength.

The results of this pilot study indicate that endodontic post design can considerably influence the retention of the post itself. Specifically, hollow fibre posts showed a higher bond strength value as compared to traditional solid posts. Interestingly, limited to the evidence obtained in our study using aself-adhesive dual-curing resin cement, the position along the root canal does not seem to remarkably affect the bond strength. In our sample, a mixed adhesive detachment at the post-cement interface was the major cause for post failure.

Overall, limited by the laboratory design of this pilot study, it can be hypothesized that these findings can have a clinical significance since the overall better performances in terms of bond strength suggest that hollow fibre posts may lead to lower rates of post detachment then traditional fibre posts, thus providing a more reliable retention of restorations of endodontically treated teeth. Additional studies with a greater sample size are however recommended to confirm these preliminary results, along with long-term, well designed clinical trials.

Funding None

Declarations

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

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