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Effect of plunger diameter on the push-out bond values of different root filling materials

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Abstract

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Aims To evaluate the effect of plunger diameter on the push-out bond strength of different root filling materials to root canal dentine.

Methodology Freshly extracted human incisors ($n = 90$) were decoronated, and the root canals were enlarged with post drills. Prepared roots were placed into a custom alignment apparatus to embed the roots vertically within self-curing acrylic resin. The specimens were randomly assigned into three groups according to the root filling system used: gutta-percha/AH Plus; Resilon/Epiphany; and fibre-reinforced composite (FRC)/Duolink resin cement. After filling, the specimens were further subdivided according to the diameter of the plunger used to employ the debonding force: 0.75, 1 and 1.25 mm. Intra-radicular bond strength was measured using the push-out test at a cross-head speed of 1 mm min^{-1}. The data were analysed statistically using Kruskal–Wallis test with Bonferroni correction at $P = 0.05$.

Results Regardless of the plunger diameter, FRC yielded the highest bond strength, followed by gutta-percha and Resilon, respectively ($P < 0.001$). In all groups, greater plunger diameter resulted in an apparent increased bond strength, but the differences were only significant in the FRC group, with the 1.25-mm plunger generating higher debonding values compared with that of its 0.75- and 1-mm versions ($P < 0.001$). In the gutta-percha and Resilon groups, the majority of specimens had adhesive failures. Roots filled with FRC exhibited more cohesive failures than those of the other test groups.

Conclusions Different plunger diameters are associated with significantly different intra-radicular push-out bond strengths of root filling systems.

Keywords: fibre-reinforced composite, gutta-percha, plunger diameter, push-out bond strength, Resilon.

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Introduction

Three-dimensional filling of the root canal with an inert filling material and creation of a fluid- and bacteria-tight seal are amongst the major goals of successful root canal treatment (Schilder 1962). Gutta-percha has been the traditional canal filling material, used in combination with various sealers (Levitan *et al.* 2003). However, this standard approach does not provide a completely hermetic seal of the root canal system (Magura *et al.* 1991, Shipper *et al.* 2004, 2005). Moreover, gutta-percha has little or no capacity for reinforcing roots after treatment (Johnson *et al.* 2000). In recent years, different filling materials and sealers have been developed on the basis of dentine adhesion technology in an attempt to seal the root canal more effectively, and to increase fracture resistance of root filled teeth (Teixeira *et al.* 2004, Gesi *et al.* 2005, Ribeiro *et al.* 2008).

Resilon (Resilon Research LLC, Madison, CT, USA) is a thermoplastic synthetic polymer-based root filling material, recently introduced with claims that it is bondable to resin-based sealers such as Epiphany (Pentron Clinical Technologies, Wallingford, CT, USA). The Epiphany system contains a self-etching primer and a dual-curable resin composite sealer, whose adjunctive use with Resilon reportedly improves

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apical seal (Shipper & Trope 2004, Shipper *et al.* 2004) and adhesion to root dentine (Gogos *et al.* 2004, Teixeira *et al.* 2004). Another approach is the use of fibre-reinforced composite (FRC) posts in combination with resin cements, which have been introduced as an alternative to cast posts to restore root filled teeth with excessive loss of tooth structure (Asmussen *et al.* 1999). FRC has a modulus of elasticity similar to that of dentine (Torbjörner *et al.* 1995, Cekic-Nagas *et al.* 2008), which enables distribution of occlusal forces more evenly within the root. This not only results in fewer root fractures but also results in less catastrophic fractures that are often repairable (Fokkinga *et al.* 2004, Gogos *et al.* 2004).

According to Gesi *et al.* (2005), reinforcement of roots by canal filling materials that utilize an adhesive interface should be reflected by improvement in the interfacial strength and dislocation resistance between the root fillings and intra-radicular dentine. The thin-slice push-out test is believed to provide a better estimation of such actual bonding effectiveness (Boschian Pest *et al.* 2002, Gesi *et al.* 2005, Goracci *et al.* 2005), because failure occurs parallel to the post cement/dentine interface, which resembles the clinical condition (Drummond *et al.* 1996, Patierno *et al.* 1996, Perdigão *et al.* 2004). Additionally, the push-out test allows for the assessment of the regional differences in bond strength amongst root levels with acceptable variability in the data distribution (Shokouhinejad *et al.* 2010). To date, many root canal filling materials have been tested using the thin-slice push-out bond strength methodology (Gesi *et al.* 2005, Goracci *et al.* 2005, Fisher *et al.* 2007). Interestingly, none of the published work has investigated the effect of plunger diameter on the push-out bond strength values to radicular dentine.

In the light of these observations, the aim of the present study was to evaluate the effect of plunger size on the push-out bond strength values of two different root filling systems and a fibre post system to radicular dentine. The null hypothesis tested was that the diameter of the plunger has no significant effect on intra-radicular push-out bond strength values of different root canal filling materials.

Materials and methods

Specimen preparation

Ninety periodontally involved, freshly extracted human anterior teeth with straight roots were used. The crowns were sectioned off below the cementoenamel junction, so that the length of all roots was adjusted to approximately 15 mm. A size 15 K-type file was placed into the root canal until it could be seen at the apical foramen, after which the apical 3 mm of each root was cut so as to discard the apical portion of roots. The root canals were enlarged with size 1-5 Peeso reamers (Dentsply Maillefer, Ballaigues, Switzerland) under water cooling to create a final post space of 12 mm length and 1.5 mm diameter.

A custom aligning apparatus was fabricated to embed each prepared root vertically within self-curing acrylic resin (Fig. 1a). The apparatus contained an axial guiding pin placed within the centre of a cylindrical mould (2 cm diameter and 1.5 cm height), which provided exact vertical alignment of the prepared roots during the autopolymerization of subsequently placed acrylic resin. Following set, cylindrical resin blocks containing the embedded root segments were removed, and the canals were

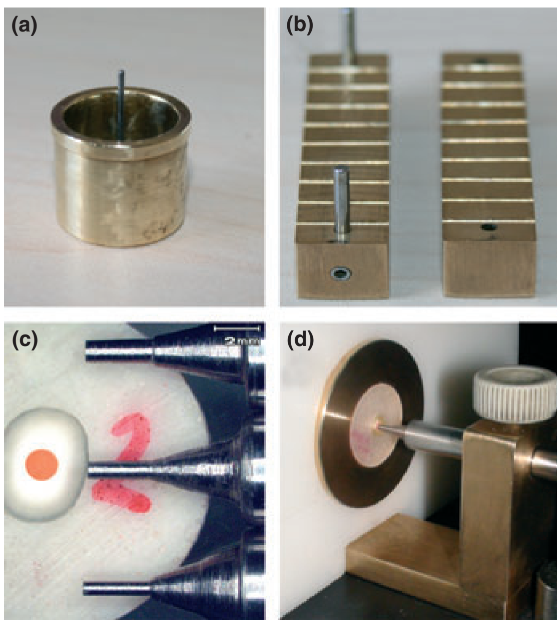


Figure 1 (a) Custom aligning apparatus with an axial guiding pin for centring the filling material. (b) Custom mould used to obtain the gutta-percha and Resilon cones. (c) Stereomicrograph of the test plunger tips (1.25, 1 and 0.75 mm from top to bottom) and a root section from group 1. The diameter of the root canal is 1.5 mm. (d) The specimen mounted in the push-out testing apparatus. Behind the centre of the specimen is a 2-mm-diameter escape hole into which the filling material is pushed by plungers. Testing load was performed at a cross-head speed of 1 mm min^{-1} until bond failure occurred.

irrigated with 5 mL sodium hypochlorite (NaOCl) followed by 5 mL 17% ethylenediaminetetraacetic acid (EDTA) to remove the smear layer. Thereafter, the specimens were irrigated with 10 mL of distilled water to avoid the prolonged effect of EDTA and NaOCl solutions. Finally, the root canals were dried with paper points.

In groups 1 and 2, the master cones were custom-made by fabricating a mould that conformed to the exact dimensions (12 mm length, 1.5 mm diameter) of the cylindrical post space (Fig. 1b). Thereafter, the specimens were randomly assigned into three groups (n = 10/group) according to root filling system used: gutta-percha + AH Plus sealer (Dentsply Caulk, Milford, DE, USA); Resilon + Epiphany sealer (Pentron Clinical Technologies); and E-glass FRC post (EverStick; Stick Tech Ltd, Turku, Finland) + Duolink resin cement (Bisco, Schaumburg, IL, USA). All materials were applied in strict adherence to the manufacturers' recommendations. Following filling, the specimens were stored at 37 °C and 100% humidity for 1 week to allow complete set of the materials.

Push-out bond strength test

The specimens were cut into 1-m-thick transverse sections in relation to the long axis of the tooth (n = 5) using a water-cooled, slow-speed precision diamond saw (Isomet 1000; Buehler, Lake Bluff, IL, USA). The thickness of each disc was measured with a digital calliper to within 0.1 mm. For each root filling system, the specimens were further subgrouped according to the diameter of the stainless steel plungers used to employ the debonding force: 0.75, 1 and 1.25 mm (Fig. 1c). Bond strengths to root canal dentine were measured using a custom push-out test apparatus (Fig. 1d), mounted on a microtensile testing device (Micro Tensile Tester; Bisco). The bond strength (MPa) at failure was calculated by dividing the load in Newtons (N) by the area of root canal filling material according to the following formula (Boschian Pest *et al.* 2002):

$$\text{Push} - \text{out bond strength (MPa)} = \frac{\text{Maximum load (N)}}{\text{Adhesion area of root canal filling (mm}^2)}$$

The adhesion area of the root canal filling material was calculated with the formula: area = $2\pi r \times h$ (Skidmore *et al.* 2006), where π = the constant 3.14, r = radius of the material pushed out, h = height of the material.

Analysis of failure modes

The failure modes were examined visually under a stereomicroscope (Olympus, Tokyo, Japan) at 40× magnification, without splitting the specimens (Skidmore *et al.* 2006). Two specimens, representative of the fracture modes from each group, were further evaluated under an EVO 50 EP environmental scanning electron microscope (SEM) (Carl Zeiss NTS GmbH, Oberkochen, Germany) at extended variable pressure (XVP) mode with carbon coating.

Statistical evaluation

Bond strength values were analysed for normal distribution using the Shapiro–Wilk test and for the homogeneity of variance with Levene's test. Thereafter, the data were analysed statistically using Kruskall–Wallis test with Bonferroni correction at P = 0.05.

Results

The push-out bond strength values are presented in Table 1 as mean ± SD. In all plunger diameters tested, FRC yielded the highest bond strength, followed by the gutta-percha and Resilon groups, respectively (Kruskal–Wallis test, P < 0.001).

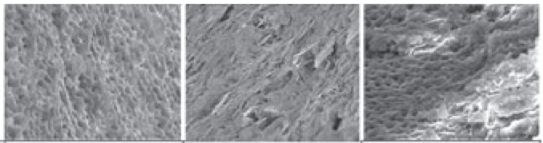
In all root filling systems tested, greater plunger diameter resulted in increased bond strength values, but the difference was only significant in the FRC group. Accordingly, the 1.25-mm plunger generated higher push-out bond strength values compared with that of its 0.75- and 1-mm versions (Kruskal–Wallis test, both P < 0.001), whilst the latter two plungers yielded similar debonding force (P > 0.017).

The fracture modes of the test groups are presented in Fig. 2. In the GP and Resilon groups, the majority of

Table 1 Push-out bond strength values (MPa, mean ± SD) of test materials with respect to the plunger diameter

	Plunger diameter (mm)		
Root filling system	0.75 mm	1 mm	1.25 mm
Resilon + Epiphany	0.81 ± 0.35^{Aa}	0.89 ± 0.30^{Aa}	1.00 ± 0.26^{Aa}
GP + AH-Plus	1.29 ± 0.30^{Bb}	1.43 ± 0.48^{Bb}	1.93 ± 0.59^{Bb}
FRC + Duolink	2.72 ± 0.69^{Cc}	3.30 ± 0.65^{Cc}	4.29 ± 0.41^{Cd}

Within each column, values with the different upper-case superscript letters are significantly different at P = 0.001 (Kruskal–Wallis test with Bonferroni correction). Within each row, values with different upper-case superscript letters are significantly different at P < 0.001(Kruskal–Wallis test with Bonferroni correction).
FRC, fibre-reinforced composite.



Filling material	Plunger diameter	Adhesive	Cohesive	Mixed
Resilon + Epiphany	0.75	9	1	0
	1	9	1	0
	1.25	8	1	1
GP + AH plus	0.75	8	2	0
	1	9	1	0
	1.25	9	1	0
FRC + Duolink	0.75	5	4	1
	1	4	4	2
	1.25	5	5	0

Figure 2 Distribution of failure modes with respect to the test group and plunger diameter. Scanning electron micrographs depict representative failure modes for each corresponding type of failure.

specimens had adhesive failures. The FRC group exhibited both cohesive failures within the resin cement and adhesive failures. In the latter group, three specimens showed mixed failures.

Discussion

Bond strength provides valuable preclinical information on the adhesive properties of materials (Cekic *et al.* 2007), and the thin-slice push-out test method has been considered a reliable technique to measure the bond strength of root canal filling materials to root dentine (Goracci *et al.* 2004). Many studies evaluating push-out bond strength have utilized a single-sized plunger (Skidmore *et al.* 2006, Fisher *et al.* 2007, Sly *et al.* 2007, Teixeira *et al.* 2009), despite the fact that the diameter of the root canal decreases towards the apical direction. To overcome this problem, Stiegemeier *et al.* (2010) utilized three different-sized plungers to closely match the diameter of the root filling materials, obtained from different root levels.

In the present study, a 1.5-mm-diameter post drill was used to standardize the bonding area in all regions of the root canal. Although tapered preparation designs that use natural canal spaces have pragmatic appeals to clinicians, preparation of the root canals with the present parallel drill also provided a cylindrical root canal space devoid of noninstrumented regions. The presence of the latter in instrumented oval-shaped canals might increase artificial canal space containing calcospherites that could increase the retention of sealer or resin cement and contact surface area, which might affect the test results (Babb *et al.* 2009). A parallel root canal preparation also minimizes the frictional resistance of the restoration to dislodgement (Patierno *et al.* 1996).

In the push-out test, the stress distribution is expected to be uniform and uniaxial, enabling the measurements to express true interfacial bond strength between dentine and the tested material (Neves *et al.* 2008). Thus, in the present study, the debonding force was exclusively applied along the central axis of the core filling material by three different-sized plungers, without stressing the surrounding root canal walls. In all groups, greater plunger diameter resulted in increased bond strength values, although the differences were not statistically significant with the exception in the FRC group. The numerical increase in bond strength can be explained by the formula: 'pressure = force/contact area' (Takehara *et al.* 2008). The null hypothesis that the diameter of the plunger has no significant effect on intra-radicular push-out bond strength values of the tested root canal filling systems should be rejected, as the different diameters of the plungers had a significant effect on push-out bond strength values of the tested FRC/Duolink samples. This finding corroborates with the results of a previous study (Goracci *et al.* 2004), suggesting that a maximum area of contact between the plunger and the specimen should be established to avoid notching of the plunger into material surface, which could interfere with the bond strength at the interface.

Analysis of the present failure modes correlates well with the results of the push-out test. Accordingly, as the resistance to dislocation increases, the failure is more likely to occur within the sealer/resin cement itself. Thus, FRC, with its higher push-out strength values, displayed more cohesive failures compared with gutta-percha and Resilon.

Regardless of the plunger diameter, the test groups showed significant differences in bond strength. The highest debonding values were observed in the FRC group, followed by the gutta-percha and Resilon groups. FRC, in combination with resin cements, exhibits good adhesive properties to dentine (Nagas *et al.* 2009), which might contribute to significantly greater bond strength values. In this regard, FRC post/Duolink combination should be considered as a post system rather than a root canal filling material. Previous studies have shown that the bond strength of the Resilon was significantly lower than that of gutta-percha and epoxy-resin sealer (Ungor *et al.* 2006, De-Deus *et al.* 2009). A possible explanation for the differences is that gutta-percha is more compactable than Resilon, which might help resist its dislodgement (Ungor *et al.* 2006).

The results of this study showed that FRC yielded statistically significant higher bond strength values than the other groups. Accordingly, the null hypothesis that the diameter of the plunger has no significant effect on intra-radicular push-out bond strength values of the tested root canal filling systems should be rejected, as the different diameters of the plungers had a significant effect on push-out bond strength values in the FRC group. As a conclusion, the plunger diameter should be considered during push-out bond strength test to accurately reveal minor differences in material bond strength properties. Further studies should confirm whether the present findings can be extrapolated to other commonly used root filling systems using different-sized plungers.

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