



ORIGINAL ARTICLE

Push-out bond strength and failure mode of single adjustable and customized glass fiber posts



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KEYWORD

Biomechanical phenomena;
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Abstract *Purpose:* To evaluate the *push-out* bond strength (PBS) and failure mode of single adjustable (SAP) and customized (CP) posts cemented to root canal dentin using conventional (RelyX Ultimate) or self-adhesive (RelyX U200) dual-cure resin cements.

Methods: Herein, 40 bovine mandibular incisors were divided into four groups (n = 10): SAP cemented with RelyX Ultimate (SAP-UT), SAP cemented with RelyX U200 (SAP-U2), CP cemented with RelyX Ultimate (CP-UT), and CP cemented with RelyX U200 (CP-U2). PBS and failure modes were analyzed. Three-way repeated measures ANOVA test followed by Tukey's test and Fisher–Freeman–Halton exact test were used for data analysis ($\alpha = 5\%$).

Results: The PBS values for SAP ($p < .05$) were higher than those for CP and were not influenced by the root third and resin cement ($p > .05$). When conventional resin cement was used, the SAP showed significant differences compared to CP ($p < .05$). When cemented with RelyX Ultimate, a higher prevalence of mixed and adhesive failures for SAP and CP, respectively, was observed ($p < .05$). For the self-adhesive resin cement, the failures were mostly adhesive ($p < .05$).

Conclusion: SAP showed better performance than CP. The root third and resin cements did not influence the PBS. The most prevalent failures were adhesive and mixed.

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1. Introduction

For many years, cast posts and cores have been the most commonly used intraradicular retainers for the restoration of teeth with excessive loss of dental hard tissue (Atlas et al., 2019; Carvalho et al., 2018; Soares et al., 2018). However, glass fiber posts (GFPs) have attracted attention as they present dentin-like physical properties, corrosion resistance, and less stress distribution compared to cast posts and cores (Carvalho et al., 2018; Marchionatti et al., 2017).

However, concerns remain regarding the fitting accuracy of GFP in larger root canals (Haralur et al., 2018; Marcos et al., 2016) as, without juxtaposition of the post, the resin cement layer tends to be thick and presents bubbles or voids, thereby predisposing to failures (ArRejaie et al., 2019; Marcos et al., 2016; Da Silva et al., 2015). Thus, the customization of GFP with resin composites is recommended (Marchionatti et al., 2017; Marcos et al., 2016). However, this procedure is time consuming.

Recently, a single adjustable post (SAP) comprising GFP and universal sleeve was proposed. The manufacturer claimed that SAP ensures better adaptation and mechanical attachment and can be used in root canals of different diameters. In addition, the need for various post sizes and drills is eliminated (Angelus, 2020). However, to the best of our knowledge, studies on SAP are still lacking.

Effective bonding between root canal dentin, cement, GFP, and composite resin in customized posts (CP) is critical for avoiding GFP debonding, microleakage, degradation, and gaps (Alshahrani et al., 2020; ArRejaie et al., 2019; Reis et al., 2018). Therefore, the choice of resin cement is fundamental for achieving long-term success in the restoration of endodontically treated teeth with GFP.

This study aims to evaluate the push-out bond strength (PBS) and failure mode of SAP and CP to root canal dentin using conventional (RelyX Ultimate) and self-adhesive (RelyX U200) dual-cure resin cements. The results were used to test (1) whether there would be significant changes in PBS of CP and SAP and (2) whether the resin cement and root third would have an influence on the PBS and failure mode.

2. Material and Methods

2.1. Study design and preparation of teeth

Herein, 40 bovine mandibular incisors were randomly divided into four groups ($n = 10$): SAP cemented with RelyX Ultimate (SAP-UT), SAP cemented with RelyX U200 (SAP-U2), CP cemented with RelyX Ultimate (CP-UT), and CP cemented with RelyX U200 (CP-U2). Table 1 presents the manufacturer's information regarding the materials tested.

Teeth were cleaned and sectioned horizontally using a double-sided diamond disk (Microdont, São Paulo, SP, Brazil) under constant air–water cooling to reach a standardized root length of 17 mm from the root apex, which was verified using a digital caliper (Mitutoyo Sul Americana, SP, Brazil). The crowns were discarded, and the roots were embedded in an acrylic resin matrix filled with condensation silicone (Heavy Body Speedex; Coltene, Switzerland).

The root canals were prepared using a crown-down technique with a #80 K-file (Dentsply/Maillefer, Ballaigues, Switzerland) as the master apical file. Root canal irrigation was performed with 1% NaOH (Biodinâmica Produtos Químicos Ltda, São Paulo, SP, Brazil) at each file change and 16% EDTA solution (Maquira, Maringá, PR, Brazil), followed by that with distilled water. The root canal was dried using suction tips and paper points and filled with lateral condensation of gutta-percha cones (Dentsply, Petrópolis, RJ, Brazil) and epoxy-resin-based sealer (Sealer 26; Dentsply, Petrópolis, RJ, Brazil). The root canal was sealed, and the specimens were stored at 37 °C and 100% humidity for 72 h. After this period, SAP and CP were performed.

The root canals were prepared using a Largo bur (#2, Angelus®, Londrina, PR, Brazil), followed by enlargement with a diamond bur (#4137, Kavo, Joinville, SC, Brazil). A 4 mm gutta-percha was left. The canals were irrigated with 16% EDTA, washed, and dried. Periapical radiographs were taken to check the quality of the root canal treatment and GFP adaptation.

Table 1 Composition of the materials used in this study.

Material	Manufacturer	Batch #	Composition
Reforpost® Glass Fiber #2	Angelus, Londrina PR, Brazil	100,889	Glass fiber (80%), pigmented resin (19%) and stainless-steel filament (1%)
Filtek Z350 XT	3 M ESPE, St. Paul, MN, USA	1,820,700,333	bis-GMA, UDMA, TEGDMA, bis-EMA, silica and zirconia particles.
Splendor® Glass Fiber	Angelus	131,118	Glass fiber (80%) and epoxy resin (20%)
Single Bond Universal	3 M ESPE, St. Paul, MN, USA	HB004559074	MDP Phosphate Monomer, Dimethacrylate resins, HEMA, vitrebond copolymer, filler, ethanol, water, initiators and silane.
RelyX Ultimate	3 M ESPE, St. Paul, MN, USA	4,471,448	Base paste: methacrylate monomers, radiopaque, silanated fillers, initiator components, stabilizers and rheological additives Catalyst paste: methacrylate monomers, radiopaque alkaline (basic) fillers, initiator components, stabilizers, pigments, rheological additives, fluorescence dye and dark cure activator for Single Bond Universal.
RelyX U200	3 M ESPE, St. Paul, MN, USA	3,993,918	Base paste: methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives. Catalyst paste: methacrylate monomers, alkaline (basic) fillers, silanated fillers, initiator components, stabilizers, pigments and rheological additives.

2.2. Anatomical customization of the GFPs

GFP was cleaned using 70% alcohol. The adhesive system (Single Bond Universal, 3 M ESPE, St. Paul, MN, USA) was applied on the fiber post and light-cured for 20 s with an LED Curing Light (Valo Cordless; Ultradent, South Jordan, UT, USA). A composite resin (Z350 XT; 3 M ESPE, St. Paul, MN, USA) was placed on the post surface and the post/resin assembly was inserted (minimum insertion depth of 13 mm) into the root canal previously isolated with a water-soluble gel and light-cured for 10 s. The post/resin assembly was removed and light-cured for 60 s.

2.3. Single adjustable post preparation

SAP was cleaned with 70% alcohol, and the universal adhesive was applied to the GFP and gently air-dried.

2.4. Cementation procedures

The root canals were washed and dried. The conventional (RelyX Ultimate, 3 M ESPE, St. Paul, MN, USA) and self-adhesive (RelyX U200; 3 M ESPE, St. Paul, MN, USA) dual-cure resin cements were handled and introduced into the root canal according to the manufacturer's instructions.

The CP and SAP were inserted into the root canal and adapted. For SAP, a universal sleeve was adapted on the post surface after insertion. Both posts were light-cured for 60 s with an irradiance of 1.400 W/cm² (Valo Cordless; Ultradent, South Jordan, UT, USA). Specimens were stored in distilled water for 7 days at 37 °C before the PBS test.

2.5. Specimen preparation

The roots were sectioned perpendicular to the long axis with a double-faced diamond disk (Extec Corp, Enfield, CT, USA) connected to a universal cutting machine (Isomet 1000; Buehler LTDA, Bluff, IL, EUA) under constant cooling to obtain two slices measuring 1 mm thick from each root third (cervical, middle, and apical), a total of six slices per root. The slice

thickness was verified using a digital caliper (Mitutoyo Sul Americana, Suzano, SP, Brazil) and stored for 24 h at 37 °C.

2.6. Push-out bond strength

The push-out test was conducted in a universal testing machine (EMIC DL 2000, EMIC, São José dos Pinhais, Paraná, Brazil) using the root slices. The punch exerted a downward force (50 kN) at a velocity of 0.5 mm/min. The area of each section was calculated using the formula: $A = \pi(R + r)\sqrt{h^2 + (R - r)^2}$, where A is the lateral area of a truncated cone, $\pi = 3.14$, R = coronal post radius, r = apical post radius, and h = thickness of root slice. The data obtained in KgF are expressed in MPa (MPa = KgF*9.8/area). The mean PBS obtained from two slices from each root third was used for the statistical analysis.

2.7. Failure mode evaluation

The pushed-out specimens were observed with a stereomicroscope loupe (EK3ST - Eikonol, São Paulo, SP, Brazil) under 40 × magnification. The failures were classified as follows: adhesive (between post/cement, post/composite, post/sleeve, sleeve/cement, composite/cement, cement/dentin), cohesive (dentin or cement), and mixed.

2.8. Statistical analysis

Normal data distribution was verified. Three-way analysis of variance (three-way ANOVA) followed by Tukey's test were used for the analysis of PBS. The failure mode was presented in relative frequency (%) and analyzed using the Fisher–Freeman–Halton exact test. All statistical analyses were performed using GraphPad Prism 7.00 (GraphPad Software, Inc., CA, US) with a significance level of 5%.

3. Results

Fig. 1 shows the PBS (MPa) for SAP and CP considering the root thirds and resin cements. No significant differences were

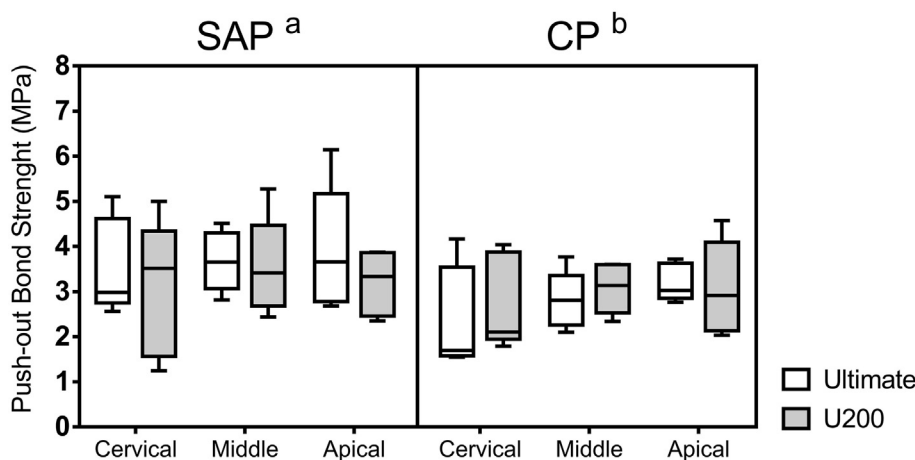


Fig. 1 Push-out Bond strength (MPa) of single adjustable and customized glass fiber posts considering the root thirds and resin cements. Different lowercase superscript letters are significantly different by three-way ANOVA ($p < .05$).

observed between post type, resin cement, and root thirds ($p > .05$). However, regardless of the post system and resin cement, PBS was higher for SAP than for CP ($p < .05$).

The failure modes according to post type, resin cement, and root third are presented in Table 2. Regardless of the root third, when RelyX Ultimate was used, SAP showed significant differences compared to CP ($p < .05$). While the overall proportion of adhesive failures when using CP was 59%, it was 38% when SAP was used. Cohesive failure in dentin occurred only in SAP. For the self-adhesive resin cement (RelyX U200), independent of the root third, no significant differences were observed regarding the post type ($p > .05$). The root thirds did not affect the fracture patterns of the SAP and CP.

4. Discussion

In this study, the first null hypothesis was rejected, as significant differences in PBS between SAP and CP were found. The resin cement and root third had no influence on PBS or the failure mode, which led to the acceptance of the second null hypothesis.

Although human teeth are preferred for *ex vivo* studies, animal teeth have been extensively used because of the ease of obtaining large quantities of sound specimens (Silva et al., 2019; Soares et al., 2016). In this study, bovine teeth were used as they are considered a reliable substitute for human teeth in bond strength studies (Soares et al., 2016). The lower PBS values found are consistent with previous reports using human teeth (Freitas et al., 2019; Goracci et al., 2004; Moura et al., 2017; Pereira et al., 2021). However, these lower values might be attributed to the different composition and tissue structure of bovine teeth compared to human teeth, as reported elsewhere (Galhano et al., 2009).

Regardless of the root third and resin cement, SAP showed a statistically higher PBS compared to CP. In this view, SAP may have promoted better post-adaptation by creating a homogeneous unit between the post, sleeve, and cement. There is also the possibility of obtaining mechanical bonding by sliding the sleeve between GFP and the canal walls, thereby increasing the retention (Angelus, 2020). Additionally, the restoration of endodontically treated teeth with flared canals by the application of an auxiliary fiber post significantly increases fracture resistance (Haralur et al., 2018; Li et al., 2011). The sleeve of the SAP may have acted similarly as an auxiliary post.

Studies have shown a decrease in PBS in the cervical-apical direction of customized and non-customized GFP (Pereira et al., 2021; Rodrigues et al., 2017). In this study, the root third did not influence the mechanical behavior of the SAP and CP. This corroborates previous studies (Freitas et al., 2019; Gomes et al., 2011; Moura et al., 2017).

Adhesion strategies significantly affect the bonding of GFP to the root canal (Alshahrani et al., 2020; Alsubait, 2020; de Moraes et al., 2013; Faria-e-Silva et al., 2012). Dual resin cements favor polymerization in critical areas of light incidence, which is the case for GFP placement. These resin cements are classified as conventional or self-adhesive. Conventional resin cements require the application of adhesives to root dentin, whereas self-adhesive does not. In this study, conventional (RelyX Ultimate) and self-adhesive (RelyX U200) dual-cure resin cements were used. Despite evidence showing no difference in PBS when different cementation strategies are used (Rodrigues et al., 2017), other studies suggest that self-adhesive resin cements exhibit better performance in GFP (Pereira et al., 2021; Sarkis-Onofre et al., 2014).

In this study, the use of self-adhesive resin cement did not influence the PBS of SAP and CP. However, when a self-adhesive resin cement was used, SAP showed better performance in the failure mode than CP. Cohesive failures in dentin occurred only in SAP, which can be explained by its increased elastic modulus (due to the presence of the sleeve). The manufacturing process of the SAP, which undergoes pultrusion using thermosetting resins and flexible fiberglass reinforcements, may also provide high physical and chemical resistance. According to the manufacturer, the pultrusion process occurs prior to the machining of the material (Angelus, 2020).

Resin cements using conventional and self-etching adhesives are suitable for the placement of GFP (Calixto et al., 2012). A study showed that conventional resin cements with self-adhesive resin cements after 24 h (Soejima et al., 2013). However, this was not observed for a longer time interval (Mendes et al., 2017; Soejima et al., 2013). A self-etch universal adhesive was used in this study. The literature shows that universal adhesives should be used in self-etch mode to improve the adhesion of GFP to the root canal (Bakaus et al., 2019; Gruber et al., 2017; Ubaldini et al., 2018). In addition, copolymerization between adhesive and cement is possible, which may explain the similar performance between the root thirds (Gruber et al., 2017; Ubaldini et al., 2018). As SAP was

Table 2 Relative frequency (%) of failure modes of the single adjustable and customized glass fiber posts considering the different root thirds and resin cements.

Failure Mode	SAP-UT	SAP-U2	CP-UT	CP-U2	Cervical		Middle		Apical	
					SAP	CP	SAP	CP	SAP	CP
Adhesive	38%	70%	59%	60%	60%	80%	40%	60%	44%	55%
Cohesive in dentin	7%	0%	0%	0%	5%	0%	5%	0%	0%	0%
Mixed	55%	30%	41%	40%	35%	20%	55%	40%	56%	45%
Fisher's exact test	p = 0.020 (*) p = 0.105 (#)		p = 1.000 (*) p = 0.589 (#)		p = 0.228 (+)		p = 0.274 (+)		p = 0.274 (+)	

(*) Comparison between SAP and CP considering each resin cement separately ($\alpha = 5\%$); (#) Comparison between the two resin cements (UT and U2) considering each post system separately ($\alpha = 5\%$); (+) Comparison between SAP and CP in the root thirds regardless of the resin cement.

recently launched, the literature still lacks studies that could lead to a better discussion of these results.

As the use of auxiliary posts may be more effective than the use of composite resin to customize GFP (Haralur et al., 2018; Li et al., 2011; Silva et al., 2021), further *in vitro* and *in vivo* studies considering posts without customization and with auxiliary posts are needed to better understand the performance of the SAP in short-and long-term periods.

5. Conclusion

The single adjustable post demonstrated greater bond strength than customized posts.

The root canal third and adhesive strategy did not influence the push-out bond strength.

The most prevalent failures were adhesive and mixed.

Ethical statement

This *in vitro* study was approved by the Animal Ethics Committee of the School of the São Leopoldo Mandic, Campinas, São Paulo, Brazil (protocol 2018/030).

CRediT authorship contribution statement

Livia Duarte Santos Lopes: Conceptualization, Methodology, Data curation, Writing – original draft, Supervision, Writing – review & editing. **Marlus Silva Pedrosa:** Data curation, Writing – original draft, Writing – review & editing. **Lara Beatriz Melo Oliveira:** Data curation, Writing – original draft, Writing – review & editing. **Sandy Maria Silva Costa:** Data curation, Writing – original draft, Writing – review & editing. **Livia Aguiar Santos Nogueira Lima:** Data curation, Writing – original draft, Writing – review & editing. **Flávia Lucisano Botelho Amaral:** Conceptualization, Methodology, Data curation, Supervision, Writing – review & editing.

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