ORIGINAL ARTICLE
Volume 19 Issue 1 2024
DOI: 10.21315/aos2024.1901.OA01
ARTICLE INFO
Submitted: 17/07/2023
Accepted: 29/01/2024
Online: 24/06/2024

A Push-out Bond Strength Study and Interface Analysis of New Porous Titanium Dental Post Luted with Resin Cement

Mohammed Nasser Alhajj[a], Zaihan Ariffin[a*], Zuryati Ab-Ghani[a], Yanti Johari[a], Yoshihito Naito[b], Mariatti Jaafar[c]

[a]*School of Dental Sciences, Universiti Sains Malaysia, Health Campus, 16150 Kubang Kerian, Kelantan, Malaysia*

[b]*Department of Oral and Maxillofacial Prosthodontics and Oral Implantology, Institute of Health Biosciences, The University of Tokushima, Tokushima 770-8503, Japan*

[c]*School of Materials and Mineral Resources, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia*

*Corresponding author: zaihan@usm.my

To cite this article: Alhajj MN, Ariffin Z, Ab-Ghani Z, Johari Y, Naito Y, Jaafar M (2024). A push-out bond strength study and interface analysis of new porous titanium dental post luted with resin cement. *Arch Orofac Sci,* **19**(1): 1–17. https://doi.org/10.21315/aos2024.1901.OA01

To link to this article: https://doi.org/10.21315/aos2024.1901.OA01

ABSTRACT

This study aimed to compare the push-out bond strength (PBS) between a new porous titanium post (PTP) and other marketed dental posts cemented with two types of dual-cure resin cement. A total of 96 extracted single-rooted human teeth were recruited. Four types of dental posts (n = 24 each), namely: stainless steel post (SSP), commercially-pure titanium post (CTP), fibre glass post (FGP), and PTP were cemented with two types of resin cements (RelyX U200 and ParaCore) and then sectioned at coronal and middle root levels. The specimens were subjected to a PBS test at a crosshead speed of 0.5 mm/min. The interface analysis was performed using a stereomicroscope and scanning electron microscope. A p-value < 0.05 was considered significant for all statistical tests. PBS recordings showed that the highest PBS mean value in RelyX group was 2.68±1.10 MPa for PTP. The differences in PBS between PTP and SSP and FGP were not significant (p = 0.098 and p = 0.075, respectively). The null hypothesis for RelyX group at both coronal and middle sections of the root was retained (p > 0.05). No failure at the post-cement interface was found in the PTP group, which was founder superior over the other posts (no gap for this interface was observed). The PTP showed similar bonding strength and adhesion to the other tested posts when using RelyX U200 cement. The PTP can be considered a new alternative option for the dental post system.

Keywords: *Dental materials; dental post; porous titanium; push-out bond strength; restorative dentistry*

INTRODUCTION

Pulpless teeth can maintain their longevity if properly treated, even without pulp. To provide support for the restoration of these teeth, intraradicular posts are commonly used, which can be obtained from the root canal (Fernandes & Dessai, 2001; Torbjörner & Fransson, 2004; Bitter & Kielbassa, 2007; Biabani-Sarand *et al.*,

 ©Penerbit Universiti Sains Malaysia. 2024
This work is licensed under the terms of the Creative Commons Attribution (CC BY) (http://creativecommons.org/licenses/by/4.0/).

2022). Dental practitioners have access to various types of endodontic posts to reinforce the core build-up of endodontically-treated teeth. These posts can either be custom-made using the lost wax technique in a dental laboratory or pre-fabricated and available in different materials such as metal, fibre-reinforced resin, and ceramic (Machado *et al*., 2017).

Among the non-metal posts, the fibre post-and-core system has undergone extensive investigation and has garnered support from both clinical and laboratory studies (Smith & Schuman, 1998; Teixeira *et al*., 2006; Theodosopoulou & Chochlidakis, 2009; de Moraes *et al*., 2013; Gbadebo *et al*., 2013, 2014; Sonkesriya *et al*., 2015; Thakur & Ramarao, 2019; Mayya *et al*., 2020; Martins *et al*., 2021). Non-metal posts have emerged due to advancements in biomaterials, adhesive systems, and the desire to improve the aesthetic aspects of dental restorations (Stewardson, 2001). These posts possess an elastic modulus similar to dentin, providing them with greater flexibility compared to metallic posts (Plotino *et al*., 2007; Hu *et al*., 2012; Gallicchio *et al*., 2022). In terms of aesthetics and fracture resistance, fibre glass post (FGP) have demonstrated higher values and a greater occurrence of desirable failure modes compared to other non-metallic options like zirconium (Habibzadeh *et al*., 2017). However, challenges such as post debonding are still encountered with this type of post in dental practice (de Moraes *et al*., 2013).

Titanium posts remain popular among metallic posts in dental practice. Titanium is an excellent biocompatible material, offering properties such as corrosion resistance, low density, low thermal conductivity, lightweight, and affordability (Branemark, 1983; Kasemo & Lausmaa, 1988; Sommer *et al*., 2020). Additionally, it can be easily shaped and textured without compromising its biocompatibility. Many studies have found no significant difference in fracture resistance between non-metallic and metallic posts (Iaculli *et al*., 2021; Silva *et al*., 2021; Alhajj, Qi *et al*., 2022).

Porous titanium, widely used in medical and dental disciplines including orthopaedics and dental implant systems, has also been explored (Spoerke *et al*., 2005; de Vasconcellos *et al*., 2008; Naito *et al*., 2013; Pałka & Pokrowiecki, 2018; Llopis-Grimalt *et al*., 2020). Porous titanium implants have been developed and tested in animal studies (Alenezi *et al*., 2013; Naito *et al*., 2013; Prananingrum *et al*., 2016), as the presence of porosity on the implant surface enhances osseointegration. Such porosity in the dental post system will enhance the retention and thus minimise or even lack debonding of the post. However, there is currently no available data on porous titanium posts (PTP), as it represents a new category of post systems. Hence, this study aims to: 1) compare the push-out bond strength (PBS) of a new PTP with commercially-pure titanium post (CTP), FGP, and stainless steel post (SSP), cemented with two types of dual-cure resin cement (RelyX U200® from 3M ESPE and ParaCore® from Coltene, Whaledent) at the coronal and middle levels of the root, and 2) analyse and compare the failure patterns (adhesion or cohesion) and post-cement-dentin interface of the tested posts at the interface level. The null hypothesis assumes no significant difference in PBS and/or failure pattern between PTP and commercially available metal and fibre posts.

MATERIALS AND METHODS

Ethical Clearance

This study was approved by the Human Ethical Committee at Universiti Sains Malaysia (JEPeM-USM) (Ref. no.: JEPeM/USM/18070325).

Sample Size Calculation

The sample size was calculated using PS Software by Dupont and Plummer (1997). The sample size was based on comparing two groups. Standard deviations and the differences between the two means were taken from a previous research (Ferrari *et al*., 2001).

The significance level was set at $\alpha = 0.05$ with 90% power. Ten samples were needed for each subgroup to evaluate the PBS. This was raised by 20% for any possible dropout, leading to 12 samples for each sub-group. Finally, 96 teeth were used to test the PBS.

Endodontic Treatment and Post Space Preparation

Single-rooted human upper anterior teeth extracted due to periodontal disease and/or for orthodontic reasons were collected for this procedure. Teeth with fully developed roots and completely formed apex were selected. All crowns of the recruited teeth were removed, and the lengths of the roots were standardised to 15±1 mm (Beltagy, 2017; Alhajj *et al.*, 2020). The measurements were done using an electronic digital caliper (INSIZE, Jiangsu, China) with a precision of ±0.1 mm. The pulp tissue was removed with a barbed broach (Dentsply Maillefer, Switzerland). Apical patency was verified (Jainaen *et al.*, 2007; Assmann *et al.*, 2012) using an ISO size 10 and 15 K-file (Dentsply Maillefer, Switzerland). Endodontic preparation was completed using the step-back technique (Upadhyay *et al.*, 2011). The irrigation of root canal was done using normal saline and sodium hypochlorite solution (5.25% NaOCl). All canals were then dried with absorbent paper points, and the obturation was done using Gutta-Percha cones and root canal sealer (EssenSeal, Produits Dentaires SA, Vevey, Switzerland). All teeth were wrapped in a wet piece of gauze and then stored in 100% humidity for one week to complete the polymerisation process of the sealant (Gopikrishna & Parameswaren, 2006). The gutta-percha was then removed from each root's coronal and middle thirds by using low-speed Gates Glidden drills number 2 and 3 (Dentsply Maillefer, Switzerland). Five millimetres of intact gutta-percha were left to preserve the apical seal. The post space preparation was accomplished using ParaPost Drill (black, no. 6) (Coltène/Whaledent Inc., USA). The post dimensions were standardised at 1.5 mm to overcome the variations in canal size. After post-space preparation, X-ray radiographs using a Planmeca ProX unit (Planmeca, Helsinki, Finland) were taken for all teeth to ensure no remnants of debris in the root canals.

Post Cementation

Before the cementation procedure, the post space was irrigated with normal saline and dried with paper points. A detailed explanation of the fabrication process of the PTP is presented elsewhere (Alhajj, Ariffin *et al.*, 2022). Briefly, an 85% wt. titanium powder was mixed with 15% wt. wax binder, as a space-holding material, to form the green compact with the required shape. The green compact was subjected to air-heating process for 2 hours to remove the wax, and then inserted into a tube furnace for 10 hours with pure argon environment to form the final product, with a maximum pore size being <75 µm. Four types of dental posts (n = 24 each), namely: SSP, CTP, FGP, and PTP were used (Table 1). The posts were cemented with RelyX U200 resin-based cement (3M ESPE, Seefeld, Germany) and ParaCore resin-based cement (Coltène, Whaledent, Altstätten, Switzerland) following the manufacturer's instructions. Another set of X-ray radiograph was taken to ensure that all posts were cemented correctly in situ. After that, the roots were sectioned perpendicular to the long axis of the tooth using a hard tissue cutter with water irrigation (Exact Apparatebau, Nordenstedt, Germany). About 1 mm at the coronal part of the root was cut and discarded to avoid contamination of the cement layer (Michida *et al.*, 2017). More details about the type of cements and type of posts used in this study are presented in Tables 1 and 2.

After that, the cutting section was made at the coronal and middle levels of the root (3.00 ± 0.2 mm thickness) using a hard tissue cutter with water irrigation (Exact Apparatebau,

Table 1 Types of post used in the study

Post	Trade name	Composition	Shape	Surface topography	Patch no.	Manufacturer
SSP	ParaPost XP SSP	Stainless steel alloy	Serrated, parallel-sided Size: 1.5 mm	Passive with X-Shape retention pattern, including cement venting	Patch no. 4,932,870 P/N 81653-89C CAT. no. P7446	Coltène/ Whaledent Inc., USA
CTP	ParaPost XP Titanium Alloy Post	Titanium alloy (Ti6AL4V)	Serrated, parallel-sided Size: 1.5 mm	Passive with X-Shape retention pattern, including cement venting	Patch no. 3,508,334 P/N 81653-88C CAT. no. P7846	Coltène/ Whaledent Inc., USA
FGP	ParaPost Fibre Lux Fibre/Resin Esthetic Post	Longitudinal glass fibres encompassed in a strong composite resin matrix	Serrated, parallel-sided Size: 1.5 mm	Passive with retention ledges	CAT. no. PF1716	Coltène/ Whaledent Inc., USA
PTP	Newly invented	Titanium powder (99.7%)	Porous, parallel-sided Size: 1.5 mm	Passive with a porous surface	CAS no. 7440-32-6 EC. no. 231-142-3	STREM Chemicals Inc., USA

Note: SSP = stainless steel post; CTP = commercially-pure titanium post; FGP = fibre glass post; PTP = porous titanium post.

Table 2 Types of cement used in the study

Trade name	Type of adhesion	Composition	Delivery form	Manufacturer
RelyX U200 cement	Dual-cure self-adhesive cement	Base paste: Methacrylate monomers containing phosphoric acid groups, Methacrylate monomers, Silanated fillers, Initiator components, Stabilisers, and Rheological additives. Catalyst paste: Methacrylate monomers, Alkaline (basic) fillers, Silanated fillers, Initiator components, Stabilisers, Pigments, and Rheological additives.	Clicker dispenser	Coltène/Whaledent Inc., USA
ParaCore cement	Dual-cure self-etching cement supplied with non-rinse conditioner and bonding A+B	ParaBond Non-Rinse Conditioner (NRC): Water, Acrylamidosulfonic acid, Methacrylate. ParaBond Adhesive A: Methacrylates, Maleic acid, Benzoyl peroxide. ParaBond Adhesive B: Ethanol, Water, Initiators. ParaCore cement: Methacrylates, Fluoride, Barium glass, Amorphous silica.	Automix syringe	Coltène/Whaledent Inc., USA

Nordenstedt, Germany). The PBS test of the sample was performed using Shimadzu Universal Testing Machine (Autograph AG-X plus, Shimadzu Corp., Japan) at a crosshead speed of 0.5 mm/min. The force was applied in Newton and then converted to mega Pascal using the following formula:

$$\begin{matrix} Pushout\ bond \\ strength\ (PBS) \end{matrix} = \frac{Force\ (Deponding\ force)}{2\pi rh\ \ (Bonded\ surface\ area)}$$

where Force is the applied load measured in Newton, *r* is the radius of the post, and *h* is the height of the section measured in mm (Dabaj *et al.*, 2018; Alhajj *et al.*, 2020).

Evaluation of Failure Mode

After testing the PBS, the remaining intact samples from each study subgroup were collected for microscope analysis to evaluate the type of failure. Stereo-microscope (Olympus SZ61) connected to a digital camera (Olympus DP-71) (Olympus Optical Co, Tokyo, Japan) with 40× magnification was used for analysis. The type of failure was classified into six modes as follows (Castellan *et al.*, 2010; Valdivia *et al.*, 2014; Pomini *et al.*, 2021): Type I: Adhesive mode post-cement (no cement visible around the post), Type II: Adhesive mode cement-dentin (no cement visible in the dentin wall), Type III: Cohesive mode in the post, Type IV: Cohesive mode in cement, Type V: Cohesive mode in dentine, and Type VI: Mixed mode (any of two or more of the above) (Fig. 1).

Post-Cement-Dentine Interface Analysis

The remaining apical thirds of the roots for some samples were sectioned in a longitudinal direction using the same hard-tissue cutting machine. The specimens were attached to aluminium pin stubs and coated with the gold using a sputter coating machine (EM SCD005, Leica, Germany) and then examined using a field-emission scanning electron microscope (FESEM, FEI, Quanta FEG 450, Netherlands). Two samples from each group were observed at 1,000× magnification with 5 kV acceleration voltage to investigate the post-cement-dentine interface.

Statistical Analysis

The collected data were entered into a master sheet (Microsoft Excel 2016), double-checked, coded, and transferred to a statistical software programme (SPSS v25, IBM Corp.) for analysis. The results were tabulated and reported descriptively as Mean±SD. All possible tests were performed to assess the differences between posts comprehensively. The differences between posts were evaluated in general (regardless of the root section and type of cement), according to the type of cement (regardless of the root section), according to the root section (regardless of the type of cement), and then according to the root section by each type of cement. The data were checked for normality distribution using the Shapiro-Wilk test, which revealed a non-normal distribution of the data ($P < 0.05$). Accordingly, a non-parametric test (Kruskal-Wallis) was used to test the null hypotheses of differences, if significant, the non-parametric Dunn's test with Bonferroni correction was used for multiple comparisons. At the same time, the Mann-Whitney U test was used for the differences in PBS based on cement type and root level. The multifactorial effect of the three variables together (post, cement, and root level) was explored using a three-way analysis of variance (ANOVA) following by two-way ANOVA series to examine the effect of each two variables (post × cement, post × root section, and cement × root section). The chi-squared test was used for the association between post type and failure mode. A p-value < 0.05 was considered significant for all tests.

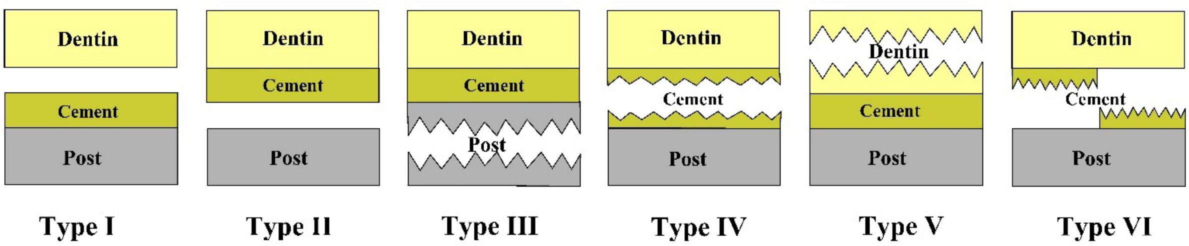

Fig. 1 Schematic representation of the different types of failure modes.

RESULTS

Push-Out Bond Strength

The PBS values of the different types of post (regardless of type of cement and section) showed that the highest mean value was 3.86±2.48 MPa (CTP). PBS recordings of the different types of post in relation to type of cement (regardless of section) showed that the highest PBS mean value in RelyX group was 2.68±1.10 MPa (PTP). For ParaCore group, the highest mean value was 5.19±2.46 MPa (CTP). Generally, the recorded values of PBS in ParaCore group were higher than those of RelyX group, except for PTP which was higher in RelyX group. PBS recordings of the different types of post in relation to section (regardless of type of cement) showed that the highest PBS mean value at the coronal section was 4.87±2.86 MPa (CTP), while, at the middle root level, the highest mean value was 2.86±1.49 MPa (CTP). Generally, the recorded values of PBS at the coronal level were higher than those at the middle level. Also, the recorded values of PBS in ParaCore-Coronal group were higher than those in ParaCore-Middle group. More details are shown in Table 1. The null hypothesis for the difference in PBS between the different types of post was rejected (p = 0.018). The post-hoc multiple comparisons showed only one significant difference between PTP and CTP (mean difference (MD) = 1.14; p = 0.030). However, the difference in PBS between PTP and SSP was not significant (MD = 1.16; p = 0.098). Similarly, the difference was not significant between PTP and FGP (MD = 1.02; p = 0.075). More details are shown in Table 3.

The null hypothesis for the difference in PBS between the different types of post luted with RelyX cement was retained (p = 0.521). However, the null hypothesis for the difference in PBS between the different types of post luted with ParaCore cement was rejected ($p < 0.001$). The post-hoc multiple comparisons showed significant difference between PTP and FGP (MD = 2.21; $p < 0.001$), between PTP and SSP (MD = 2.75; $p < 0.001$), and between PTP and CTP (MD = 2.96; $p < 0.001$). The null hypothesis for the difference in PBS between the different types of post at the coronal section of the root was rejected (p = 0.006),

Table 3 Means and SDs of the BPS of the different types of post, and the test of null hypothesis for the differences (in MPa)

Parameter		SSP	CTP	FGP	PTP	*p*-value for differences*
By type of post						
		3.62±2.34^{a}	3.86±2.48^{ab}	3.48±1.90^{abc}	2.46±1.08^{ac}	0.018
By type of cement						
	RelyX U200	2.25±1.35	2.54±1.67	2.52±1.91	2.68±1.10	0.521
	ParaCore	4.98±2.33^{a}	5.19±2.46^{ab}	4.44±1.35^{ab}	2.23±1.03^{c}	< 0.001
By root section						
	Coronal	4.66±2.65^{a}	4.87±2.86^{ab}	4.54±1.78^{abc}	2.82±0.94^{ad}	0.006
	Middle	2.57±1.35	2.86±1.49	2.42±1.37	2.09±1.10	0.356
By type of cement and root section						
RelyX U200	Coronal	2.89±1.51	2.69±1.76	3.77±1.95	3.18±0.67	0.342
	Middle	1.61±0.81	2.39±1.65	1.27±0.66	2.18±1.24	0.165
ParaCore	Coronal	6.44±2.37^{a}	7.05±1.91^{ab}	5.31±1.22^{ab}	2.47±1.06^{c}	< 0.001
	Middle	3.53±1.08a	3.33±1.21^{ab}	3.56±0.80^{abc}	2.00±0.99^{bd}	0.004

Notes: *Kruskal-Wallis tests for null hypothesis of no difference followed by post-hoc non-parametric tests for multiple comparisons. Values with the same superscript letters represent a non-significant difference; *p*-value is considered significant at < 0.05. SSP = stainless steel post; CTP = commercially-pure titanium post; FGP = fibre glass post; PTP = porous titanium post.

and retained for the difference at the middle section of the root ($p = 0.356$). The post-hoc multiple comparisons revealed significant difference between PTP and CTP (MD = 2.04; $p = 0.025$), and between PTP and FGP (MD = 1.72; $p = 0.014$) (Table 3).

The null hypotheses for RelyX group at both coronal and middle sections of the root were retained ($p > 0.05$). However, the null hypotheses for ParaCore group at both coronal and middle sections of the root were rejected ($p < 0.05$). The post-hoc multiple comparison test revealed significant differences in PBS between PTP and other post types at the coronal section of the root. At the middle section, there were significant differences between PTP and FGP (MD = 1.56; $p = 0.011$) and between PTP and SSP (MD = 1.53; $p = 0.011$), while there was no significant difference between PTP and CTP (MD = 1.33; $p = 0.053$) (Table 3).

The multifactorial analysis of variance (ANOVA) for the interaction effect of post, cement, and root section (Table 4) revealed significant effect for all factors together ($p = 0.001$), and for each factor independently ($p < 0.001$, each). The two-way ANOVA series revealed significant interaction effect for post and cement ($p < 0.001$). The effect of post was seen to be low compared to cement (Type III sum of squares value = 55.111). However, the interaction effect of post and root section was found to be non-significant ($p = 0.180$), with the lowest total effect (Type III sum of squares value = 16.331).

Failure Mode

One-hundred sixty-four samples out of 192 samples were available for failure mode analysis. The observed types of failure for all samples were Type I, Type II, and Type VI (Fig. 2 and Fig. 3). In total, the most prevalent mode was Type VI (57.3%), followed by Type II (30.5%), and Type I (12.2%). Type II was the most prevalent mode in SSP (40.5%), while Type VI was the most prevalent in CTP, FGP and PTP (46.5%, 57.1%, 91.9%, respectively). No prevalence of Type I (post-cement failure) was noticed in PTP. The distribution of failure modes among different types of post and cement was significant ($p < 0.001$ and $p = 0.001$, respectively). Concerning the distribution of failure modes among the different root sections, the most prevalent mode in both coronal and middle sections was Type VI followed by Type II, with no significant association ($p = 0.219$). More details are shown in Table 5 and Figure 4.

Table 4 Three-way ANOVA tests of PBS for the interaction effect of post, cement and root level

Source	Type III sum of squares	df	Mean square	F	*p*
Post	55.111	3	18.370	9.463	< 0.001
Cement	140.870	1	140.870	72.562	< 0.001
Section	145.325	1	145.325	74.857	< 0.001
Post × Cement	79.642	3	26.547	13.675	< 0.001
Post × Section	16.331	3	5.444	2.804	0.041
Cement × Section	10.707	1	10.707	5.515	0.020
Post × Cement × Section	35.046	3	11.682	6.017	0.001
Error	341.683	176	1.941		
Total	2,985.335	192			
Corrected Total	824.715	191			

Note: p-value is considered significant at < 0.05.

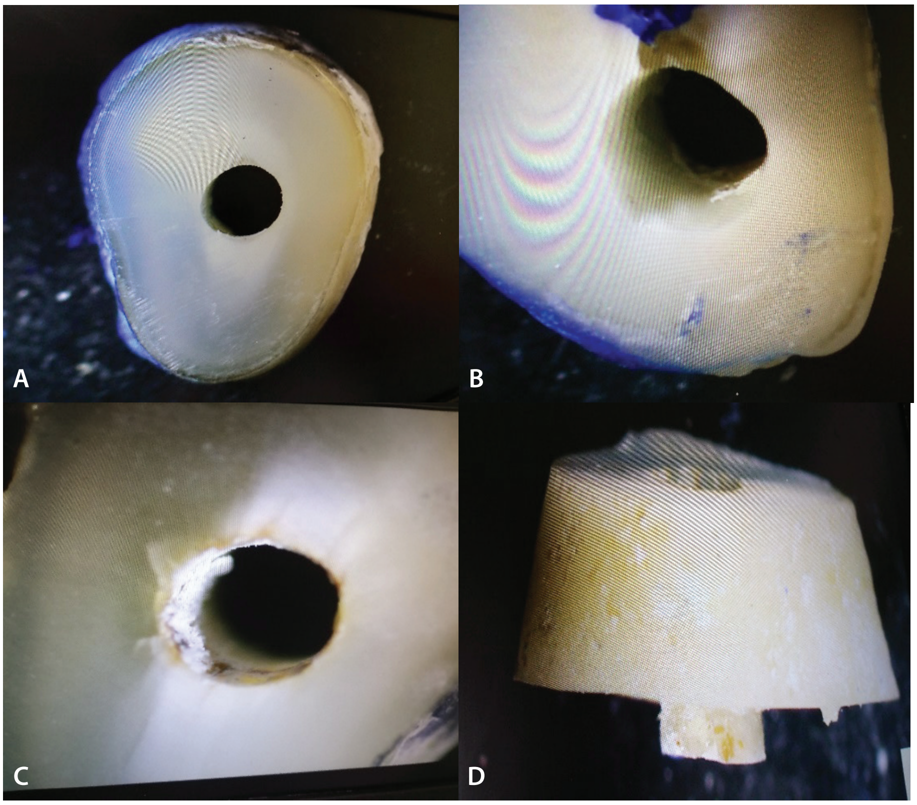

Fig. 2 Different types of failure modes as seen on the teeth; Type II (A and B), and Type VI (C and D).

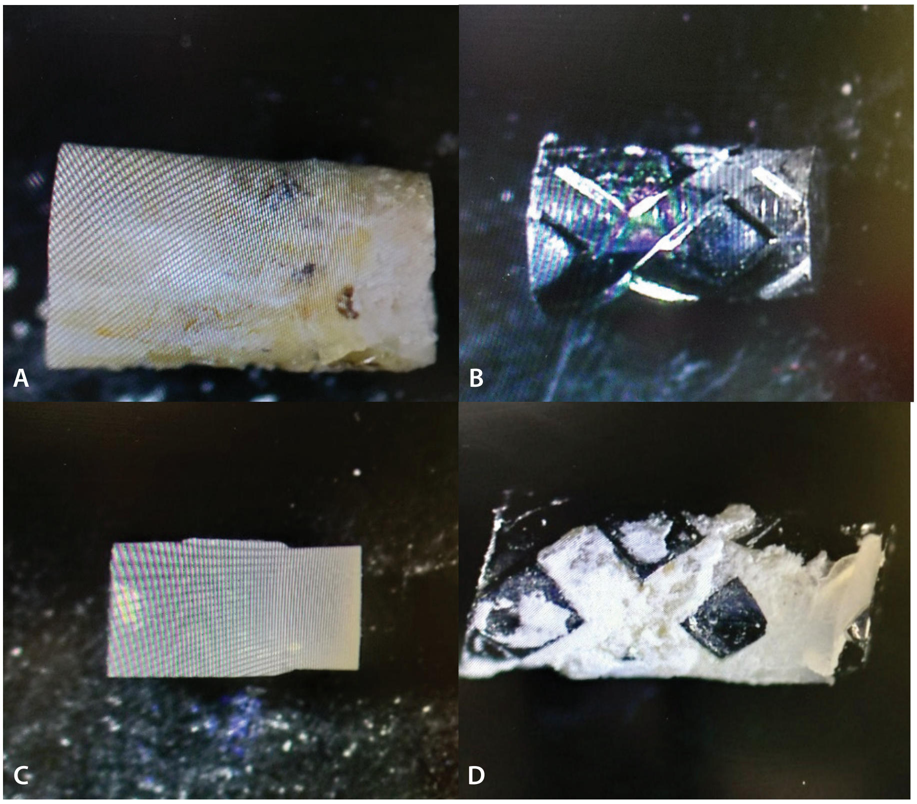

Fig. 3 Different types of failure modes as seen on the posts; Type II (A, [PTP]), Type I (B and C, [SSP and FGP]), and Type VI (D, [SSP]).

Table 5 Distribution of failure modes among the different types of post, cement and section

Parameter	Failure mode			
	Type I	**Type II**	**Type VI**	***p****
By type of post				
SSP	9 (21.4)	17 (40.5)	16 (38.1)	< 0.001
CTP	7 (16.3)	16 (37.2)	20 (46.5)	
FGP	4 (9.5)	14 (33.3)	24 (57.1)	
PTP	0 (0.0)	3 (8.1)	34 (91.9)	
By type of cement				
RelyX U200	5 (6.1)	35 (42.7)	42 (51.2)	0.001
ParaCore	15 (18.3)	15 (18.3)	52 (63.2)	
By root section				
Coronal	13 (16.5)	21 (26.6)	45 (57.0)	0.219
Middle	7 (8.2)	29 (34.1)	49 (57.6)	
Total	20 (12.2)	50 (30.5)	94 (57.3)	

Note: *Chi-square test was used; *p*-value is considered significant at < 0.05.

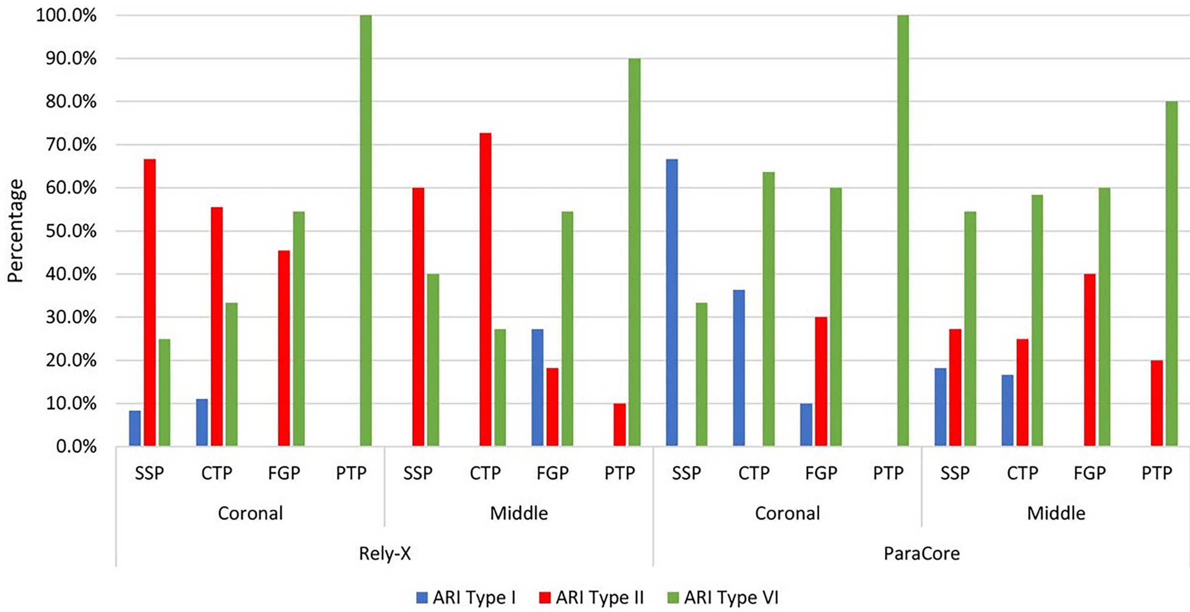

Fig. 4 Different types of failure modes according to type of post, type of cement, and root section.

Post-Cement-Dentin Interface

Figure 5 depicts the different views of the post-cement-dentin interface for the different types of post. It can be noticed that the cement-dentin interface seems to be stronger in SSP and CTP with ParaCore cement than RelyX cement (the space between cement and dentin is wider with RelyX). While, the post-cement interface seems to be better in CTP than in SSP. However, there were no observable differences in the post-cement and cement-dentin interfaces in FGP with both types of cement. For PTP, the post-cement interface seems to be the best over the other posts (no clear line for this interface was observed), while the cement-dentin interface seems to be better with RelyX cement than ParaCore cement.

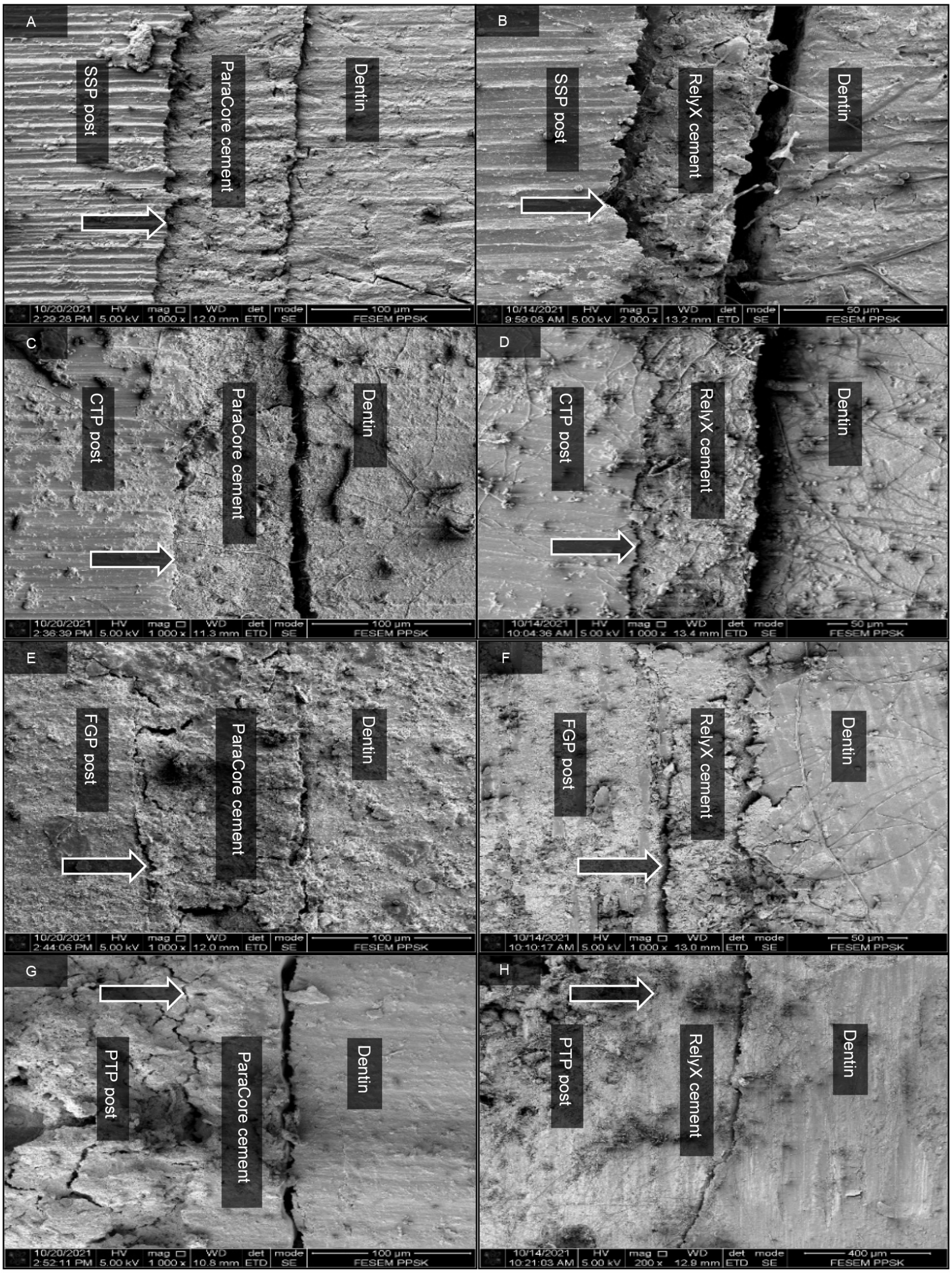

Fig. 5 Post-cement-dentin interface (at the apical third) as seen under FESEM; (A) SSP with ParaCore cement, and (B) SSP with RelyX cement, (C) CTP with ParaCore cement, and (D) CTP with RelyX cement, (E) FGP with ParaCore cement, and (F) FGP with RelyX cement, (G) PTP with ParaCore cement, and (H) PTP with RelyX cement (black arrow refers to the cement-post interference).

DISCUSSION

In the present study, the novel PTP was tested with other prefabricated dental posts. The results revealed significant differences in PBS between ParaCore and RelyX U200 cements (regardless of the type of posts or type of sections), with higher values for ParaCore cement. In a recent systematic review and meta-analysis of in-vitro studies, Miotti *et al.* (2020) found significant differences in bonding strength in favour of conventional cements, which support the current findings that ParaCore (self-etching) cement was more retentive than RelyX U200 (self-adhesive) cement. The results of a more recent study by Chou *et al.* (2022) are also in agreement with these results. Another study by Pulido *et al.* (2016) also supporting our findings of the lower values of self-adhesive cements compared to self-etching cements. A possible explanation for the differences between conventional and self-adhesive cements might be related to the filler content of the cement. The weight of the filler content of the conventional cement is higher than that of self-adhesive cement. Moreover, the average size of content particles is relatively larger in conventional cements than that in self-adhesive cement (Ferracane *et al.*, 2011).

The cylindrical-shaped PTP were used in the present study to standardise the comparison with the other dental posts. However, one of the study's main objectives is to introduce the PTP as an anatomical post that can mimic the shape of the root canal. The invented post in the present study is metallic made of pure titanium hopefully can give more advantageous properties than the current titanium posts available in the market. Also, this invented post can be fabricated as custom-made so that it will fit well along the root canal with a minimal amount of dentin reduction and thinner layer of the luting cement. The most important point is that the new modification with this post; that is the porosity. This PTP is porous in both internal and external structures. The porosity inside the post will help in reducing the weight of the post as well as decreasing the undesirable rigidity which will make it more flexible. The surface porosity on the post will make it rougher; the property that will enhance its retention by increasing the micro-interlocking between the cement and the post surface. In addition, the PTP can be fabricated with the core as one piece which has the benefits of eliminating the possible incompatibility between the pre-fabricated dental post and core materials. Another possible reason that makes the tapered post showing higher bond strength is the fact that this type of dental posts can fit the root canal thoroughly from apical to coronal (Wiskott *et al.*, 1999; Bagheri, 2013; Sahafi *et al.*, 2015; Farid *et al.*, 2018).

Generally, the present results revealed a PBS value ranging from 2.46±1.08 to 3.86±2.48 MPa, with the CTP had the highest value. However, when the results were linked to the types of cement, the PBS value was the highest for PTP in RelyX U200 group. Whereas, the highest PBS value in ParaCore group was for CTP. Hence, the hypothesis be partially accepted as the PTP had the highest value in RelyX U200 group, while it had not the highest value in ParaCore group. The finding of the CTP in ParaCore group could be compared to that found in the study by Al-harbi and Nathanson (2003). Our findings of different values of the same posts when using different types of cement, with higher values in ParaCore cement, might be attributed to the fact that self-etching cement is better in bonding than self-adhesive cements (self-etching cement may provide stronger bonding due to the separate etching step that allows for better micromechanical retention) (Borer *et al.*, 2007; Orucoglu *et al.*, 2014).

For intra-group comparisons, the PTP showed the highest bonding strength values compared to the other tested posts in the RelyX group (regardless of root section), and were comparable to other tested posts in the middle section of the root (regardless of the type of cement). These results provide interesting evidence for the possibility of using the PTP as alternative post of the endodontically treated teeth. The multiple comparison test revealed non-significant differences between PTP and SSP, and between PTP and FGP. This could be considered as another evidence that the tested posts had approximately similar effect on the PBS, making the PTP a viable option for dental post system.

Another important finding in this study is the distribution of the failure mode for the adhesion behaviour of the tested dental posts, particularly the PTP. Overall, the results revealed that the most frequent failure mode was Type VI failure mode (mixed mode), with most prevalence in the PTP group followed by FGP. The most interesting finding in this regard is that there was no prevalence of failure mode Type I (failure at the post-cement interface) in the PTP group. This finding refers directly to the intimate contact between the luting cement (both types of cement) and the porous post. The presence of the porous surface can effectively enhance the bonding between the post and cement. Form the results of failure modes distribution, it can be noticed that the PTP behaves as the same as the other tested dental posts, particularly SSP and FGP. Although the cement-dentin interface is associated directly to the luting cement and its ability to bond to the dentin, it is obvious that more prevalence of failure at cement-dentin interface is correlated with less prevalence of failure at post-cement interface. This fact was confirmed in the present study as PTP had no prevalence of failure at the post-cement interface in relation to both types of cement as well as at both root sections.

The FESEM views of the longitudinal sections of the apical sections revealed obviously important differences at the post-cement-dentin interface. The lines between the SSP and cement and between CTP and cement (for both types of cement) are clearly visible. However, the lines between both types of cement and PTP are completely invisible. This interesting and important finding is significant evidence for the strong micro-interlocking connection between PTP and both types of cement. Another notable finding linked to the PTP is the absence of any gap between the cement and surface of the root dentin. This finding could explain the low prevalence of Type II failure mode in PTP group.

In summary, all these findings pose a promising and potential use of the PTP as an alternative to the commercially available dental post systems. However, some limitation should be acknowledged. Testing the PTP as a custom-made post was not performed. The reason was that the dimensions of the PTP were standardised to the other tested posts. The fracture resistance and flexural strength of the new post (with actual dimensions) were not tested as the present study focused mainly on the new characterisations of the post surface (porosity) and its effect on the bonding strength. More mechanical tests are highly recommended in future studies such as flexural strength test with the actual dimensions of the post and also tensile bond strength test to provide an overall view of the post behaviour. Moreover, the computer-aided design/computer-aided manufacturing (CAD/CAM) technology is also recommended to be investigated with the PTP. Future in-vivo studies can be then conducted to validate the use of the PTP in real clinical trials with follow-up period to provide a view of the survival rate of the post inside the oral environment.

CONCLUSION

Within the limitations of the present study, the following conclusions could be drawn. The PTP showed similar bonding strength to the other tested posts when using RelyX U200 cement. The adhesion of the PTP was comparable to or better than other tested posts, showing no prevalence of adhesive post-cement failure mode with both types of cement. Furthermore, the FESEM views of the post-cement-dentin interface showed optimal micro-interlocking adhesion between PTP and both types of cement. Based on these findings, the PTP can be considered as a new alternative option for dental post system.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Universiti Sains Malaysia (USM) Fellowship and the USM Research University Grant (1001/PPSG/8012282).

REFERENCES

Alenezi A, Naito Y, Andersson M, Chrcanovic BR, Wennerberg A, Jimbo R (2013). Characteristics of 2 different commercially available implants with or without nanotopography. *Int J Dent*, **2013**: 769768. https://doi.org/10.1155/2013/769768

Alhajj MN, Ariffin Z, Ab-Ghani Z, Johari Y, Naito Y, Jaafar M (2022). A novel moldless porous titanium formulae for dental post system: Part 1 – Development and characterization. *Mater Today Proc*, **66**(5): 2670–2675. https://doi.org/10.1016/j.matpr.2022.06.492

Alhajj MN, Qi CH, Sayed ME, Johari Y, Ariffin Z (2022). Fracture resistance of titanium and fiber dental posts: A systematic review and meta-analysis. *J Prosthodont*, **31**(5): 374–384. https://doi.org/10.1111/JOPR.13428

Alhajj MN, Salim NS, Johari Y, Syahrizal M, Abdul-Muttlib NA, Ariffin Z (2020). Push-out bond strength of two types of dental post luted with two types of cement at two different root levels. *Acta Stomatol Croat*, **54**(3): 263–272. https://doi.org/10.15644/asc54/3/4

Al-harbi F, Nathanson D (2003). In vitro assessment of retention of four esthetic dowels to resin core foundation and teeth. *J Prosthet Dent*, **90**(6): 547–555. https://doi.org/10.1016/j.prosdent.2003.09.014

Assmann E, Scarparo RK, Böttcher DE, Grecca FS (2012). Dentin bond strength of two mineral trioxide aggregate-based and one epoxy resin-based sealers. *J Endod*, **38**(2): 219–221. https://doi.org/10.1016/J.JOEN.2011.10.018

Bagheri R (2013). Film thickness and flow properties of resin-based cements at different temperatures. *J Dent (Shiraz)*, **14**(2): 57–63.

Beltagy TM (2017). Fracture resistance of rehabilitated flared root canals with anatomically adjustable fiber post. *Tanta Dent J*, **14**(2): 96–103. https://doi.org/10.4103/tdj.tdj_16_17

Biabani-Sarand M, Bahari M, Abed-kahnamoui M, Ebrahimi-Chaharom ME, Shahi S (2022). Effect of intraradicular reinforcement strategies on the fracture strength of endodontically treated anterior teeth with overflared canals. *J Clin Exp Dent*, **14**(1): e79–e84. https://doi.org/10.4317/JCED.58862

Bitter K, Kielbassa AM (2007). Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: A review. *Am J Dent*, **20**(6): 353–360.

Borer RE, Britto LR, Haddix JE (2007). Effect of dowel length on the retention of 2 different prefabricated posts. *Quintessence Int*, **38**(3): e164–e168.

Branemark PI (1983). Osseointegration and its experimental background. *J Prosthet Dent*, **50**(3): 399–410. https://doi.org/10.1016/S0022-3913(83)80101-2

Castellan CS, De Freitas Santos-Filho PC, Soares PV, Soares CJ, Cardoso PEC (2010). Measuring bond strength between fiber post and root dentin: A comparison of different tests. *J Adhes Dent*, **12**(6): 477–485. https://doi.org/10.3290/j.jad.a17856

Chou IC, Wang HT, Chen YC, Hsu YF, He WH (2022). Comparing the bond strength of fiber post cementation in the root canal using pre- and co-curing procedures with the same self-etching bonding system. *J Dent Sci*, **17**(4): 1689–1696. https://doi.org/10.1016/J.JDS.2022.02.016

Dabaj P, Kalender A, Eldeniz AU (2018). Push-out bond strength and SEM evaluation in roots filled with two different techniques using new and conventional sealers. *Materials*, **11**(9): 1620. https://doi.org/10.3390/MA11091620

de Moraes AP, Cenci MS, de Moraes RR, Pereira-Cenci T (2013). Current concepts on the use and adhesive bonding of glass-fiber posts in dentistry: A review. *Appl Adhes Sci*, **1**(1): 4. https://doi.org/10.1186/2196-4351-1-4

de Vasconcellos LMR, de Oliveira MV, de Alencastro Graça ML, de Vasconcellos LGO, Carvalho YR, Cairo CAA (2008). Porous titanium scaffolds produced by powder metallurgy for biomedical applications. *Mater Res*, **11**(3): 275–280. https://doi.org/10.1590/S1516-14392008000300008

Dupont WD, Plummer Jr WD (1997). *PS* power and sample size program available for free on the Internet. *Control Clin Trials*, **18**(3): 274. https://doi.org/10.1016/S0197-2456(97)00074-3

Farid F, Rostami K, Habibzadeh S, Kharazifard M (2018). Effect of cement type and thickness on push-out bond strength of fiber posts. *J Dent Res Dent Clin Dent Prospects*, **12**(4): 277–282. https://doi.org/10.15171/joddd.2018.043

Fernandes AS, Dessai GS (2001). Factors affecting the fracture resistance of post-core reconstructed teeth: A review. *Int J Prosthodont*, **14**(4): 355–363.

Ferracane JL, Stansbury JW, Burke FJT (2011). Self-adhesive resin cements – Chemistry, properties and clinical considerations. *J Oral Rehabil*, **38**(4): 295–314. https://doi.org/10.1111/J.1365-2842.2010.02148.X

Ferrari M, Vichi A, Grandini S, Goracci C (2001). Efficacy of a self-curing adhesive-resin cement system on luting glass-fiber posts into root canals: An SEM investigation. *Int J Prosthodont*, **14**(6): 543–549.

Gallicchio V, Lodato V, De Santis R, Rengo S (2022). Fracture strength and failure modes of endodontically treated premolars restored with compact and hollow composite posts subjected to cyclic fatigue. *Materials*, **15**(3): 1141. https://doi.org/10.3390/MA15031141

Gbadebo OS, Ajayi DM, Dosumu Oyekunle OO, Shaba PO (2014). Randomized clinical study comparing metallic and glass fiber post in restoration of endodontically treated teeth. *Indian J Dent Res*, **25**(1): 58–63.

Gbadebo SO, Ajayi DM, Abiodun-Solanke IM, Sulaiman AO (2013). Survival of glass fiber post retained endodontically treated teeth preliminary report. *Afr J Med Med Sci*, **42**(3): 265–269.

Gopikrishna V, Parameswaren A (2006). Coronal sealing ability of three sectional obturation techniques – Simplifill, Thermafil and warm vertical compaction – Compared with cold lateral condensation and post space preparation. *Aust Endod J*, **32**(3): 95–100. https://doi.org/10.1111/j.1747-4477.2006.00030.x

Habibzadeh S, Rajati HR, Hajmiragha H, Esmailzadeh S, Kharazifard M (2017). Fracture resistances of zirconia, cast Ni-Cr, and fiber-glass composite posts under all-ceramic crowns in endodontically treated premolars. *J Adv Prosthodont*, **9**(3): 170–175. https://doi.org/10.4047/JAP.2017.9.3.170

Hu C, Shao LQ, Wang LL, Zhou SY, Ai J (2012). Flexure strength and elastic modulus of four types of dental fiber posts. *Key Eng Mater*, **519**: 269–272. https://doi.org/10.4028/www.scientific.net/KEM.519.269

Iaculli F, Rengo C, Lodato V, Patini R, Spagnuolo G, Rengo S (2021). Fracture resistance of endodontically-treated maxillary premolars restored with different type of posts and direct composite reconstructions: A systematic review and meta-analysis of in vitro studies. *Dent Mater*, **37**(9): e455–e484. https://doi.org/10.1016/j.dental.2021.06.007

Jainaen A, Palamara JEA, Messer HH (2007). Push-out bond strengths of the dentine–sealer interface with and without a main cone. *Int Endod J*, **40**(11), 882–890. https://doi.org/10.1111/J.1365-2591.2007.01308.X

Kasemo B, Lausmaa J (1988). Biomaterial and implant surfaces: A surface science approach. *Int J Oral Maxillofac Implants*, **3**(4): 247–259.

Llopis-Grimalt MA, Arbós A, Gil-Mir M, Mosur A, Kulkarni P, Salito A *et al.* (2020). Multifunctional properties of quercitrin-coated porous Ti-6Al-4V implants for orthopaedic applications assessed in vitro. *J Clin Med*, **9**(3): 855. https://doi.org/10.3390/jcm9030855

Machado J, Almeida P, Fernandes S, Marques A, Vaz M (2017). Currently used systems of dental posts for endodontic treatment. *Procedia Struct Integr*, **5**: 27–33. https://doi.org/10.1016/j.prostr.2017.07.056

Martins MD, Junqueira RB, de Carvalho RF, Lacerda MFLS, Faé DS, Lemos CAA (2021). Is a fiber post better than a metal post for the restoration of endodontically treated teeth? A systematic review and meta-analysis. *J Dent*, **112**: 103750. https://doi.org/10.1016/j.jdent.2021.103750

Mayya A, Naik R, Mayya SS, Paul MP (2020). Fracture resistance of endodontically treated maxillary premolars with a longer single post and shorter double posts of different sizes: An in vitro study. *J Int Soc Prev Community Dent*, **10**(2): 183–184. https://doi.org/10.4103/jispcd.JISPCD_472_19

Michida SM de A, Dal Piva AM de O, Tribst JPM, Souza ROA, Lombardo GHL, Bottino MA *et al.* (2017). Resin push-out bonding strength to root canal dentin: Effect of the irrigation solution application prior to post cementation. *Braz Dent Sci*, **20**(2): 85–92. https://doi.org/10.14295/bds.2017.v20i2.1426

Miotti LL, Follak AC, Montagner AF, Pozzobon RT, da Silveira BL, Susin AH (2020). Is conventional resin cement adhesive performance to dentin better than self-adhesive? A systematic review and meta-analysis of laboratory studies. *Oper Dent*, **45**(5): 484–495. https://doi.org/10.2341/19-153-L

Naito Y, Bae J, Tomotake Y, Hamada K, Asaoka K, Ichikawa T (2013). Formability and mechanical properties of porous titanium produced by a moldless process. *J Biomed Mater Res Part B Appl Biomater*, **101B**(6): 1090–1094. https://doi.org/10.1002/jbm.b.32919

Orucoglu H, Yavuz T, Demir N, Ozturk N, Ozturk B (2014). Push-out bonding strengths of four different dowel systems luted with two different adhesive systems. *J Adhes Sci Technol*, **28**(22–23): 2305–2315. https://doi.org/10.1080/01694243.2014.958911

Pałka K, Pokrowiecki R (2018). Porous titanium implants: A review. *Adv Eng Mater*, **20**(5): 1700648. https://doi.org/10.1002/adem.201700648

Plotino G, Grande NM, Bedini R, Pameijer CH, Somma F (2007). Flexural properties of endodontic posts and human root dentin. *Dent Mater*, **23**(9): 1129–1135. https://doi.org/10.1016/j.dental.2006.06.047

Pomini M, Pfeifer CS, Piovezan Fugolin A, Piccolli VM, de Paula Ramos RA, Xediek Consani RL (2021). Effect of conventional and experimental silanes on the adhesion of fiberglass posts to root canals: In vitro study. *Saudi Endod J*, **11**(3): 393–399. https://doi.org/10.4103/sej.sej_297_20

Prananingrum W, Tomotake Y, Naito Y, Bae J, Sekine K, Hamada K *et al.* (2016). Application of porous titanium in prosthesis production using a moldless process: Evaluation of physical and mechanical properties with various particle sizes, shapes, and mixing ratios. *J Mech Behav Biomed Mater*, **61**: 581–589. https://doi.org/10.1016/j.jmbbm.2016.04.021

Pulido CA, de Oliveira Franco APG, Gomes GM, Bittencourt BF, Kalinowski HJ, Gomes JC *et al.* (2016). An in situ evaluation of the polymerization shrinkage, degree of conversion, and bond strength of resin cements used for luting fiber posts. *J Prosthet Dent*, **116**(4): 570–576. https://doi.org/10.1016/j.prosdent.2016.02.019

Sahafi A, Benetti AR, Flury S, Peutzfeldt A (2015). Retention of root canal posts: Effect of cement film thickness, luting cement, and post pretreatment. *Oper Dent*, **40**(4): E149–E157. https://doi.org/10.2341/14-159-L

Silva CF, Cabral LC, Navarro de Oliveira MN, da Mota Martins V, Machado AC, Blumenberg C *et al.* (2021). The influence of customization of glass fiber posts on fracture strength and failure pattern: A systematic review and meta-analysis of preclinical ex-vivo studies. *J Mech Behav Biomed Mater*, **118**: 104433. https://doi.org/10.1016/j.jmbbm.2021.104433

Smith CT, Schuman N (1998). Prefabricated post-and-core systems: An overview. *Compend Contin Educ Dent*, **19**(10): 1013–1018.

Sommer U, Laurich S, de Azevedo L, Viehoff K, Wenisch S, Thormann U *et al.* (2020). In vitro and in vivo biocompatibility studies of a cast and coated titanium alloy. *Molecules*, **25**(15): 3399. https://doi.org/10.3390/molecules25153399

Sonkesriya S, Olekar ST, Saravanan V, Somasunderam P, Chauhan RS, Chaurasia VR (2015). An in vitro comparative evaluation of fracture resistance of custom made, metal, glass fiber reinforced and carbon reinforced posts in endodontically treated teeth. *J Int Oral Health*, **7**(5): 53–55.

Spoerke ED, Murray NG, Li H, Brinson LC, Dunand DC, Stupp SI (2005). A bioactive titanium foam scaffold for bone repair. *Acta Biomater*, **1**(5): 523–533. https://doi.org/10.1016/j.actbio.2005.04.005

Stewardson DA (2001). Non-metal post systems. *Dent Update*, **28**(7): 326–332. https://doi.org/10.12968/denu.2001.28.7.326

Teixeira ECN, Teixeira FB, Piasick JR, Thompson JY (2006). An in vitro assessment of prefabricated fiber post systems. *J Am Dent Assoc*, **137**(7): 1006–1012. https://doi.org/10.14219/jada.archive.2006.0323

Thakur A, Ramarao S (2019). A comparative evaluation of fracture resistance of endodontically treated premolar teeth reinforced with different prefabricated and custom-made fiber-reinforced post system with two different post lengths: An in vitro study. *J Conserv Dent*, **22**(4): 376–380.

Theodosopoulou JN, Chochlidakis KM (2009). A systematic review of dowel (post) and core materials and systems. *J Prosthodont*, **18**(6): 464–472. https://doi.org/10.1111/j.1532-849X.2009.00472.x

Torbjörner A, Fransson B (2004). A literature review on the prosthetic treatment of structurally compromised teeth. *Int J Prosthodont*, **17**(3): 369–376.

Upadhyay V, Upadhyay M, Panday RK, Chturvedi TP, Bajpai U (2011). A SEM evaluation of dentinal adaptation of root canal obturation with GuttaFlow and conventional obturating material. *Indian J Dent Res*, **22**(6): 881.

Valdivia ADCM, Novais VR, Menezes M de S, Roscoe MG, Estrela C, Soares CJ (2014). Effect of surface treatment of fiberglass posts on bond strength to root dentin. *Braz Dent J*, **25**(4): 314–320. https://doi.org/10.1590/0103-6440201300143

Wiskott HWA, Belser UC, Scherrer SS (1999). The effect of film thickness and surface texture on the resistance of cemented extracoronal restorations to lateral fatigue loading. *Int J Prosthodont*, **12**(3): 255–262.