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ASSESSMENT OF PUSH OUT BOND STRENGTH AND CEMENT THICKNESS FOR OVAL ROOT CANALS RESTORED WITH DIFFERENT POST TECHNIQUES

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ABSTRACT

Objectives: The aim of the present study was to evaluate the push out bond strength of fiber posts to oval shaped root canals using different post techniques and correlation of bond strength values to different cement thicknesses at different post level in different post techniques.

Methods: A total of thirty-two recently extracted human mandibular first premolars with oval root canals were selected and stored in normal saline solution. The teeth were horizontally sectioned 2 mm coronal to the cementoenamel junction with a double-faced diamond disk in a slow-speed handpiece with copious coolant. Root canal treatment was done for all teeth using a standardized technique. The teeth were then randomly divided into four equal groups (n=8) according to the post and core system used: Group I: Single circular post technique, Group II: Relined post technique, Group III: Double circular post technique, Group IV: Oval post technique. For each sample, the roots were cut horizontally, perpendicular to the long axis of the root using low speed diamond saw under water coolant to obtain three 2 mm ± 0.1 thick root specimens representing cervical, middle and apical third of the root. The resin cement thickness around each specimen obtained after slicing were measured using scanning electron microscope (SEM) at eight standardized points around the circumference of the slice; between the canal wall and the fiber post perimeter. Each root slice was subjected to compressive loading at a crosshead speed of 1 mm/min via a computer controlled Universal testing machine to record the maximum failure load in Newton. The push out bond strength was calculated by dividing the recorded peak load by the surface area of each slice.

Results: As regards to the mean push out bond strength values for the post techniques, there was a statistically significant difference between mean push out bond strength of different post techniques where oval post technique showed the statistically significant highest mean push out bond strength. Relined technique showed statistically significant lower mean value followed by double circular technique. Single circular technique showed the statistically significantly lowest

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mean push out bond strength. Regarding the push out bond strength values for the root levels regardless of the post techniques, there was a statistically significant difference between mean push out bond strength at different root levels where there was no statistically significant difference between coronal and middle root levels and both showed statistically significantly higher mean push out bond strength than apical root level for all post techniques.

Conclusions: The use of single circular post technique in oval or flared canals is not a good option for long term clinical service. Decreasing the cement thickness space around the post systems in oval canals will improve the push out bond strength of posts to dentinal walls of the root canals. The introduction of oval posts for restoration of endodontically treated teeth with oval and flared root canals gives promising results in push out bond strength tests.

KEYWORDS: Fiber post, Oval canals, flared canals, Oval fiber post, Glass fiber post, Self-adhesive resin cement, Push-out bond strength, cement thickness.

INTRODUCTION

Restoration of endodontically treated teeth have always been a challenge in prosthodontics. These teeth are considered at a high risk of unfavorable fractures due to extensive loss of coronal tooth structure due to caries and the endodontic procedure itself. Most likely, these teeth will require the placement of posts for retention of the core material before the preparation of teeth to receive an extra-coronal full coverage restoration.

Numerous post systems have been offered over the years, from cast posts to different shapes of ready-made metallic posts and lately the most widely used nowadays the glass fiber posts [1]. Cast metal posts have been used long time ago by the clinicians and was considered the gold standard due to the perfect adaptation of these posts to any shape of the root canal. However, the use of these posts had declined owing to the extra complicated clinical and laboratory procedures needed for their fabrication [2]. Additionally, the big drawback of cast metal posts had been reported in the literature to be their high modulus of elasticity (200 Gpa) resulting in uneven stress distribution between the post and the intra-radicular dentin which may cause fracture of the weaker part which is presented in the root structure rendering the tooth non restorable and indicated for extraction [3].

Hence, the shift to the use of different prefabricated metal post systems that was favored by many clinicians; these posts presented a fast, easy and cheap technique; however, the esthetic outcome was disappointing [2,4]. Among the recently popular ready-made post systems used nowadays is the glass fiber post. These posts have gained their attractiveness due to many advantages: very good esthetic results, easy procedure, less clinical time, easy retrievability and preservation of the remaining tooth structure [5,6 ,7]. On the top of that is the main advantage of the glass fiber post which is the compatibility of its modulus of elasticity with that of the dentin, giving it a unique property that aids in protection of endodontically treated teeth from root fractures [7,8]. These posts are cemented to dentin with adhesive resin cements, thus allowing this assembly to become biomimicry, therefore more uniform stress distribution is allowed throughout the radicular dentin and less susceptibility to unrestorable fractures is reached [8,9].

Nevertheless, the drawback that was detected within the fiber posts is its circular cross section which render this treatment option to be perfect in cases of root canals with circular cross section only [9,10,11]. Upon considering the oval-shaped and flared canals in the dentition, it was considered to have a high percentage due to widening of the root canals during endodontic procedures, extensive carious lesions, old restorations and anatomical and morphological reasons [9,12,13] and the circular fiber post systems are considered to be a poor treatment option with these oval shaped canals.

Previous reports showed that 90% of the mandibular first premolars have oval shaped canals starting at the CEJ and extending up to almost 2mm from the anatomical apex [5,8,13]. To be able to place the circular fiber post in the oval flared canals, additional shaping of the root canal must be done through sound intra-radicular dentin removal to match the shape of a larger circular fiber post to the flared canals, this will compromise the tooth fracture resistance [7] and increase the risk of root perforation or fracture [3,14,15]. Otherwise, cementation of the mismatched circular fiber post within the oval canals associated with an excessive thick layer of resin cements [16,17] leading to the presence of voids or gaps from the luting process. This will generate high stresses at the non-homogenous luting interphase resulting in compromised bond strength of the post [7,9]. Furthermore, the polymerization shrinkage of thick adhesive resin cement will further magnify the stress concentration and failure in adhesive bonding[7].

Many attempts have been tried to overcome this shortcoming with oval canals. Among them are the trial of relining the circular post with composite resin to obtain adaptation to the post before cementation [18], the use of several small posts or the use of accessory post technique in which supplementary posts are added along with the main fiber post in an attempt to improve adaptation and decrease luting cement volume [7,19,20]. Oval glass fiber posts have been introduced to overcome the clinical limitations of circular fiber posts and to extend the indications of the fiber posts to include all types and shapes of root canals. Therefore, a better post fit, adhesion and retention strength can be achieved [17,21,22].

One of the most common failures occurring with the use of the fiber posts is the post debonding [9,10,23,24]. Endodontic irrigants and sealers [25], presence of thick smear layer, high configuration of the root canal (c-factor), imperfect moisture control [26], and presence of voids or gaps associated with a thick layer of cement are reported to be the main causes of decreased retention values of the fiber posts to the root canal [27,28]. Debonding with large cement film thicknesses has been reported by some retrospective clinical studies [29] which highlighted the important value of reaching an ideal reduced thickness of resin cement and obtaining a proper fit of fiber post shape and size into the post spaces inside root canals [10].

Several methods have been used to assess the bond strength of fiber posts to root dentin; micro tensile, pull-out and push-out tests have been tried for this purpose. Thus, the aim of the present study was to evaluate the bond strength of fiber posts to oval-shaped root canals using different post techniques and correlation of bond strength values to different cement thicknesses at different post level in different post techniques. The null hypothesis was that different post techniques and different post levels would have no effect on the push out bond strength of the fiber posts.

MATERIALS AND METHODS

Teeth selection and preparation

A total of thirty-two recently extracted human mandibular first premolars were selected and stored in normal saline solution. Only single-rooted premolar teeth with an oval shaped root canals were included in this study; the teeth were described as oval if the ratio of the long to short diameters was ≥ 2, measured at 5mm away from the apex. Other inclusion criteria were: teeth with straight roots with similar size and shape, mean root length of 14 mm from buccal CEJ, completely formed apices and intact clinical crowns. Teeth with open apex, caries, cracks, fractures, resorption were excluded from the study.

Teeth were cleaned from deposits, stains or calculus using ultrasonic scalers and were disinfected in 0.5% sodium hypochlorite solution. Then teeth were stored in distilled water at room temperature until the experiment starts. The teeth were horizontally sectioned 2 mm coronally to the cementoenamel junction with a double-faced diamond disk in a slow-speed handpiece with copious coolant, so that length of the root was standardized in all samples to be 14 mm.

Root canal preparation:

The teeth were embedded vertically in epoxy resin blocks (Polypoxy 700, polymer, chemical industries for construction Co., CIC, Egypt). so that 1 mm apical to the cementoenamel junction was kept above the epoxy resin blocks.

Conservative access cavity was done for all teeth and the working length was adjusted to be 1 mm shorter than apical foramen. The root canals were instrumented using protaper rotary instrument (Dentsply Maillefer, Ballaigues, Switzerland). Master apical file was selected to be F5. 3% NaOcl was used as an irrigation solution between files. Paper points were used to dry the root canals. Then, the canals were obturated using ProTaper gutta-percha cones and a sealer (AH plus, Dentsply Maillefer, USA) [(7)]. Root canal treatment for all teeth was done by the same operator.

Post space preparation:

For all samples, gutta percha was removed using size #2,3 gates glidden (Mani Inc., Tochigi, Japan) to a depth of 10 mm leaving 4 mm apical seal. The teeth were then randomly divided into four equal groups (n=8) according to the post and core system used.

Group I: Single circular post technique.

Group II: Relined post technique.

Group III: Double circular post technique.

Group IV: Oval post technique.

Regarding groups I, II, III, post space was prepared, 10 mm in depth, using special drill size # 3 (Rely x fiber post drill, 3M, ESPE). As for group IV, the post space was prepared using finishing drill size # 2 (Macro-lock oval post drill, RTD, France) up to the same 10 mm in depth as the previously prepared three groups. Afterwards the root canals for all teeth were irrigated using saline solution and dried with paper points.

Post cementation

The posts were cemented in the root canals according to the different techniques as follows:

Group I: The post was cleaned with an alcohol swab and then dried. Rely X Unicem 2 automix self-adhesive resin cement (3M, ESPE) was applied inside the root canal with the endo tip to allow void free application of the cement inside the root canal, then rely x fiber post size # 3 (3M, ESPE) was placed and centralized inside the root canal and manually stabilized using steady finger pressure for 1 minute [(9)]. The excess cement was removed using a cotton swab and the cement was light polymerized with LED curing light blue phase (Ivoclar, Vivadent, Schaan, Liechtenstein) for 40s through the post in an occluso-apical direction.

Group II: Before cementation of the post, the post was customized to the shape of the canal using composite resin. The canals were lubricated with water-soluble gel and composite resin Filtek Z 250 (3M, ESPE) was applied around the 3 M rely x fiber post size # 3 that was used in group I. the post with the surrounding composite was placed inside the canal and the post was allowed in and out the canal to customize the shape of the post according to the canal shape. The relined post was light polymerized while still in position inside the root canal for 5s then removed from the canal and polymerized for 60s on each side of the post. The root canals were irrigated using saline and dried with paper points. The cementation process was done as previously mentioned within group I.

Group III: the same process was done as was previously mentioned in group I, but the main post was placed (3M Rely X fiber post size # 3) up to the post space and one accessory post (3M Rely X fiber post size # 1) was positioned beside the main one as apical as possible without pressure.

Group IV: Macro-Lock Illusion post X-RO size # 2 was cemented inside the root canals following the same cementation protocol as that used for group I.

Composite core fabrication:

The extended coronal parts of the posts were sectioned leaving 3 mm above the remaining tooth structure. To restore the coronal part, core formers were used to standardize the dimensions of the core build up. The dimensions of the core were 7 mm height and 4 mm in diameter. Filtek Bulkfill posterior composite (3M^{TM}, ESPE^{TM}) was used to build up all the coronal part of all the teeth. All the teeth were prepared to receive full coverage crowns with 1 mm thickness chamfer finish line and 2 mm ferrule height. The taper of the prepared coronal part was standardized using parallel milling machine (Bravo, Mariotti, Forli FC, Italy).

Specimen preparation for push-out bond strength test

For each sample, the roots were cut horizontally, perpendicular to the long axis of the root using low speed diamond saw under water coolant to obtain three 2 mm ± 0.1 thick root specimens representing coronal, middle and apical third of the root. The thickness of each specimen was measured using digital caliper (Pachymeter, Electronic Digital Instruments, China). The coronal slice representing the coronal third of the root was adjusted to be 2 mm from the cemento-enamel junction, the middle slice representing the middle third of the root was adjusted to be 5 mm from the cemento-enamel junction, and the apical slice representing the apical third of the root was adjusted to be 7 mm from the cemento-enamel junction. (Fig.1) Each section was coded and photographed from apical

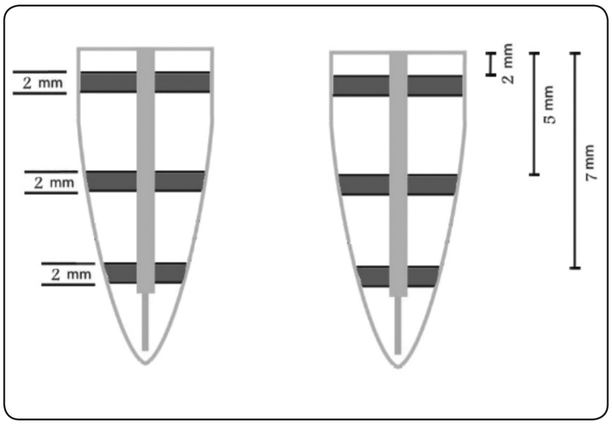

Fig. (1): Diagram showing specimen slices prepared for push-out bond strength test.

and coronal surfaces using a stereomicroscope (SZ-PT; Olympus, Tokyo, Japan) at an original magnification of 65x. Calibration was performed by comparing an object of known length, a ruler in this study, using the ‘‘Set Scale’’ tool generated by the image analysis software (Image J; NIH, Bethesda, MD). The diameter of the post was then measured, and the radius was calculated to measure the surface area for each section.

Cement thickness measurements Fig. (2)

The cervical, middle and apical slices of each root for all samples were dipped in 90 % alcohol, air dried, fixed on a metallic stub. [30]. The resin cement thickness around each specimen obtained after slicing were measured using scanning electron microscope (SEM). SEM image was documented for each slice at (x 200, x400, x800) magnification and eight standardized points were recorded around the circumference of each slice; between the canal wall and the fiber post perimeter. The measurements were recorded using the SEM software [30].

Push-out bond strength testing:

Each root slice was mounted in a custom made loading fixture [metallic block with circular cavity at the middle, this cavity for specimen housing having a central hole to facilitate displacement of extruded post, then subjected to compressive loading at

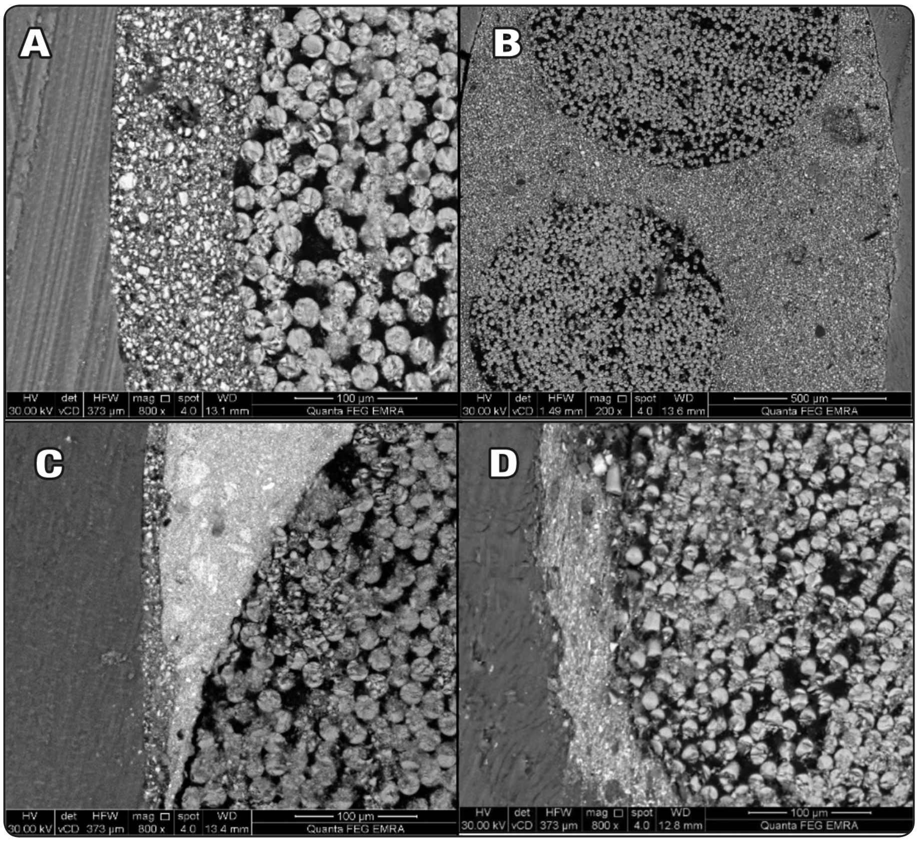

Fig. (2). SEM images comparing the cement thickness across different groups: (A) Circular post technique. (B) Double circular post technique. (C) Relined post technique. (D) Oval post technique.

a crosshead speed of 1 mm/min via a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA).

Load applied by plunger of 1, 0.8, 0.5 mm diameter corresponding to the radicular thirds (coronal, middle and apical) to be tested. The plunger tip was sized and positioned to touch only the post, without stressing the surrounding dentin, in apical coronal direction to push the post toward the larger diameter, thus avoiding any limitation to the post possibly owing to the canal taper. This way, it was guaranteed that the overlaying dentin was sufficiently supported during the loading process. The maximum failure load was recorded in Newton and converted into MPa. The bond strength was calculated from the recorded peak load divided by the computed surface area as calculated by the following formula as regards to groups I, II, III: [31]

$[A = (3.14x\ r^1 X\ 3.14x\ r^2)\ L]$, Where:

r^1 apical radius, r^2 cervical one,

$L= [(r1-r2)2+h^2]^{0.5}$ and h is the thickness of the sample in millimetres].

Regarding group IV with oval post, the surface area was calculated as was stated before in a previous study [21].

Failure manifested by extrusion of the post and confirmed by sudden drop along load-deflection curve recorded by Nexygen computer software. The push-out bond strength was determined for each root slice.

Statistical Analysis

Data were presented as mean and standard deviation (SD) values. Repeated measures Analysis of Variance (ANOVA) was used to study the effect of post technique, root level and their interaction on mean shear bond strength and cement thickness. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. Pearson's correlation coefficient was used to study the correlation between cement thickness and shear bond strength. The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

1. Push out bond strength

Repeated measures ANOVA results showed that post technique (*P*-value <0.001, Effect size = 0.995) and root level (*P*-value <0.001, Effect size = 0.859) had a statistically significant effect on mean push out bond strength. The interaction between the two variables had a statistically significant effect on mean push out bond strength indicating that the variables are dependent upon each other. Table. (1)

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between push out bond strength of the different post techniques revealed that oval post showed the statistically significant highest mean push out bond strength. Relined post technique showed statistically significantly lower mean value followed by double circular technique. Single circular technique showed the statistically significant lowest mean bond strength. (Fig. 3, table 2, 4).

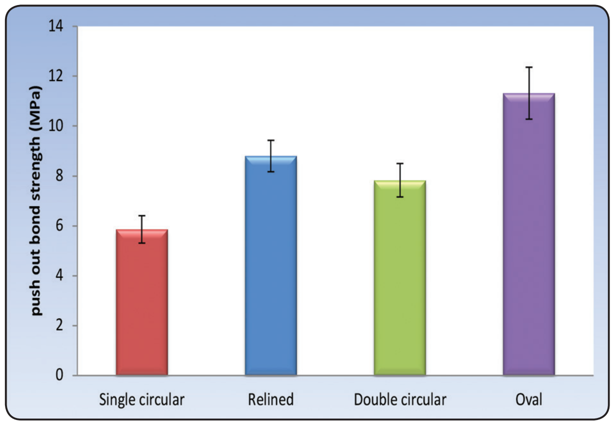

Fig. (3). Bar chart representing mean and standard deviation values for push out bond strength for different post techniques.

TABLE (1) Repeated measures ANOVA results for the effect of different variables on mean push out bond strength.

Source of variation	Type III Sum of Squares	Df	Mean Square	*F*-value	*P*-value	Effect size *(Partial eta squared)*
Post technique	231.414	3	77.138	1143.840	<0.001*	0.995
Root level	21.540	2	10.770	97.586	<0.001*	0.859
Post technique x Root level interaction	4.959	6	0.826	7.488	<0.001*	0.584

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05

TABLE (2) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between push out bond strength of the different post techniques

Single circular		Relined		Double circular		Oval		*P*-value	Effect size *(Partial eta squared)*
Mean	SD	Mean	SD	Mean	SD	Mean	SD		
5.86 ^{D}	0.55	8.8 ^{B}	0.63	7.83 ^{C}	0.67	11.32 ^{A}	1.04	<0.001	0.995

***: Significant at P ≤ 0.05, Different superscripts are statistically significantly different**

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between push out bond strength at different root levels revealed that there was no statistically significant difference between coronal and middle root levels; both showed statistically significantly higher mean bond strength than apical root level. (Fig. 4, table 3,4).

2. Cement thickness

Repeated measures ANOVA results for cement thickness showed that both post technique (*P*-value <0.001, Effect size = 0.994) and root levels (*P*-value <0.001, Effect size = 0.963) had a statistically significant effect on mean cement thickness. The interaction between the two variables had a statistically significant effect on mean cement thickness indicating that the variables are dependent upon each other. Table (5)

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between cement thickness of the four post techniques revealed that single circular technique showed the statistically significantly highest mean cement thickness. Double circular

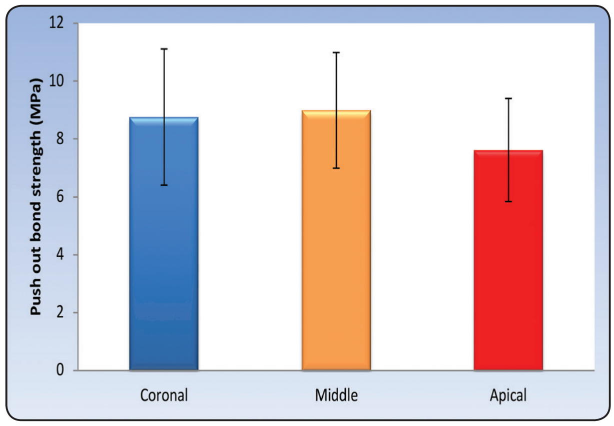

Fig. (4) Bar chart representing mean and standard deviation values for push out bond strength at different root levels.

TABLE (3) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between shear bond strength of different Root levels regardless of post technique.

Coronal		Middle		Apical		*P*-value	Effect size *(Partial eta squared)*
Mean	SD	Mean	SD	Mean	SD		
8.76 ^{A}	2.35	8.99 ^{A}	2	7.62 ^{B}	1.78	<0.001*	0.859

: Significant at P ≤ 0.05, Different superscripts are statistically significantly different

TABLE (4) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between push out bond strength values with different interactions of variables

Root level	Single circular		Relined		Double circular		Oval		*P*-value	Effect size *(Partial*
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Coronal	6 ^{DE}	0.09	8.87 ^{BF}	0.37	7.88 ^{CF}	0.24	12.28 ^{AE}	0.2	<0.001*	0.991
Middle	6.3 ^{DE}	0.25	9.44 ^{BE}	0.36	8.53 ^{CE}	0.4	11.67 ^{AF}	0.24	<0.001*	0.978
Apical	5.28 ^{DF}	0.53	8.11 ^{BG}	0.15	7.07 ^{CG}	0.17	9.99 ^{AG}	0.39	<0.001*	0.967
P-value	0.003*		<0.001*		<0.001*		<0.001*			
Effect size *(Partial eta squared)*	0.547		0.650		0.692		0.897			

: Significant at P ≤ 0.05, A, B, C, D superscripts in the same row indicate statistically significant difference between post techniques,E, F, G superscripts in the same column indicate statistically significant difference between root levels

TABLE (5) Repeated measures ANOVA results for the effect of different variables on mean cement thickness.

Source of variation	Type III Sum of Squares	Df	Mean Square	*F*-value	*P*-value	Effect size *(Partial eta squared)*
Post technique	527602.130	3	175867.377	879.506	<0.001*	0.994
Root level	87422.914	2	43711.457	413.170	<0.001*	0.963
Post technique x Root level interaction	94590.639	6	15765.107	149.015	<0.001*	0.965

df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05

technique showed statistically significantly lower mean value followed by oval technique. Relined technique showed the statistically significantly lowest mean cement thickness, (Fig.5, table 6).

The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between cement thicknesses of different root levels revealed that coronal root level showed the statistically significant highest mean cement thickness followed by the middle root level Whereas the apical level showed the statistically significant lowest mean cement thickness. (Fig.6, table 7,8).

Correlation between cement thickness and push out bond strength whether at the coronal, middle or apical levels showed that there was a statistically significant inverse correlation between cement thickness and push out bond strength

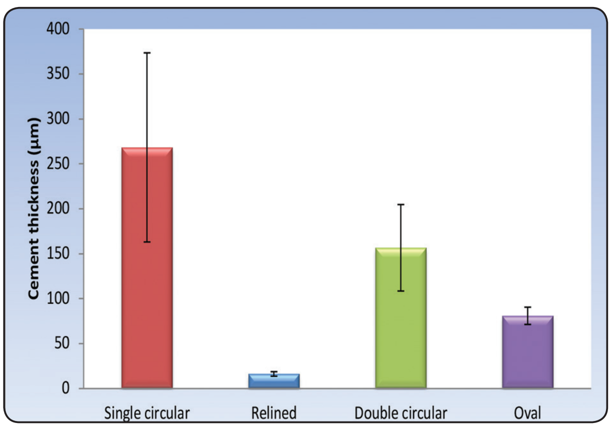

Fig. (5). Bar chart representing mean and standard deviation values for cement thickness of different post techniques regardless of root level.

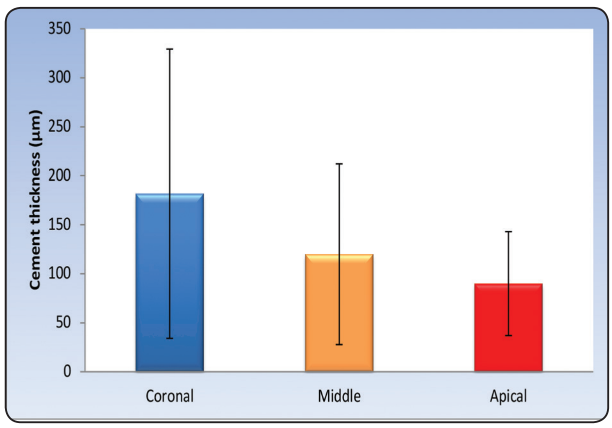

Fig. (6). Bar chart representing mean and standard deviation values for cement thickness of different root levels regardless of post technique

TABLE (6) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between cement thickness of the four post techniques.

Single circular		Relined		Double circular		Oval		*P*-value	Effect size *(Partial eta squared)*
Mean	SD	Mean	SD	Mean	SD	Mean	SD		
268.3 [A]	105.2	16.28 [D]	2.45	156.67 [B]	48.11	80.97 [C]	9.63	<0.001*	0.994

: Significant at P ≤ 0.05, Different superscripts are statistically significantly different

TABLE (7). The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between cement thicknesses of different Root levels regardless of post technique.

Coronal		Middle		Apical		*P*-value	Effect size *(Partial eta squared)*
Mean	SD	Mean	SD	Mean	SD		
181.69 [A]	147.6	119.97 [B]	92.22	90 [C]	53.04	<0.001*	0.963

**Significant at P ≤ 0.05, Different superscripts are statistically significantly different*

TABLE (8) The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between cement thickness values with different interactions of variables.

Root level	Single circular		Relined		Double circular		Oval		*P*-value	Effect size *(Partial*
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Coronal	395.13 [AE]	31.34	17.49 [D]	1.62	220.94 [BE]	8.8	93.19 [CE]	4.03	<0.001*	0.990
Middle	285.54 [AF]	19.03	17.72 [D]	0.77	130.77 [BF]	5.93	72.85 [CF]	1.99	<0.001*	0.990
Apical	151.23 [AG]	1.21	13.62 [D]	2.12	118.3 [BG]	12.07	76.85 [CF]	3.77	<0.001*	0.988
P-value	<0.001*		0.734		<0.001*		0.007*			
Effect size *(Partial eta squared)*	0.982		0.040		0.941		0.486			

A, B, C, D superscripts in the same row indicate statistically significant difference between post techniques,

E, F, G superscripts in the same column indicate statistically significant difference between root levels

TABLE (9) Results of Pearson's correlation coefficient for the correlation between cement thickness and push out bond strength at different root levels.

Coronal		Middle		Apical	
Correlation coefficient (r)	*P*-value	Correlation coefficient (r)	*P*-value	Correlation coefficient (r)	*P*-value
-0.724	<0.001*	-0.785	<0.001*	-0.637	0.003*

****: Significant at P ≤ 0.05***

(r = -0.724, P-value <0.001), (r = -0.785, P-value <0.001) and (r = -0.637, P-value = 0.003), respectively. An increase in cement thickness is associated with a decrease in push out bond strength and vice versa. Table (9)

DISCUSSION

Over the years, the increased use of fiber reinforced posts has been well documented, owing to the unique property of matched elastic modulus to the human dentin. This property along with the use of the resin luting cements for cementation provided a perfect bond between dentin and fibre post allowing uniform stress distribution throughout the root dentin and therefore reducing the incidence of root fractures. [32,33,34,35]

Commonly, the fiber posts are rounded in cross section, however, the oval root canals have been stated as a common configuration with a high percentage in some teeth. Oval fiber posts have been introduced in the market so that better adaptation and improved bond strength to the dentin canal walls can be achieved within the oval and flared canal shapes. [36]

The aim of this study was to evaluate the effect of different post techniques used with oval canals on the push-out bond strength between the fiber post and root canal dentin at different root canal levels. Mandibular human premolars with oval canals were selected in this study to simulate clinical conditions, [34] however, the human teeth represented a relatively large variation in morphology size and mechanical properties of the specimens.[37,38] This limitation has been overcome through standardization of the dimensions of the roots for the selected teeth, endodontic treatment and post space preparation with similar dimensions throughout all the selected teeth for all the tested groups.

Inadequate bonding strength resulted in debonding between post and root canal dentin. The push out bond strength test was used in this study to determine the bond strength between different post techniques in oval root canals. This test gives rise to more uniform stress distribution than conventional shear or tensile tests. [23] The fracture takes place parallel to the dentin adhesive interface within the push out test, which makes it a true shear test. [39] The shear stresses arise with the push out test is comparable to the actual clinical conditions, thus representing the true interfacial bond strength between dentin canal walls and the fiber post.[10,23] Among the different research methods used, the push out test examined the bond strength of fiber posts to root with less data distribution,variability, more uniform values and less premature failures. [40]

The null hypothesis of this study was rejected as the push out bond strength of the fiber post was influenced by both the different post techniques and different post levels along the canal length. The results of this study revealed that there was a statistically significant difference between mean push out bond strength values of different post techniques regardless of root levels. The oval post technique showed statistically significant highest mean push out bond strength values. This could be attributed to the increased adaptation of the oval post to the oval canal shape resulting in decreased thickness of surrounding luting cement. This is confirmed by the results of the cement thickness measurements done using the scanning electron microscope, which revealed lower cement thickness readings than single circular and double circular post techniques.

Up to date, in the literature, the studies correlating the push out bond strength of the post with the shape of the post and cement thickness along the root are controversial. Some researchers proved that a thinner cement thickness resulted in greater bond strength values, others confirmed [41,42] that a thick cement layer between canal walls and fiber post causes adhesive post failures and debonding. On the contrary,[28,43] some authors did not support these results and showed that a thicker luting cement improved the retention of fibre posts. (44,45) While, other in vitro studies concluded that alterations in cement thickness layer do not significantly influence the retentive strength of the cement with the fibre post. (46,47)

Regarding the single circular post technique, the authors point of view was assured through analysing the results of this group which showed least push out bond strength values and largest cement thickness layer. The excessively thick cement layer might have resulted in low bond strength values and higher frequencies of post debonding. It is worth mentioning that this thick layer of cement that fills the space between the oval canal wall and the ill-fitting circular post has led to the presence of bubbles or voids within the cement layer. This represented areas of weakness within the whole assembly. Additionally, the large cement thickness might be an influencing factor in induced shrinkage stresses caused by polymerization shrinkage of the luting cement which is known as C-factor. This might have intensified the stress concentration and subsequent failure in bonding. This gives another explanation to the causes of the weak bond strength showed within the single circular post technique group. This analysis has been well documented previously in several previous studies. (28,48)

As regards to the results of the double circular post technique group which revealed lower statistically significant bond strength values than oval post technique but higher statistically significant bond strength values than single circular post technique. This technique has been tried as an attempt to improve adaptation of the post to oval canal walls and decrease luting cement thickness. However, the results were not promising, this might be contributed to the air entrapment within the cement layer upon insertion of the second post, as was observed within the scanning electron microscope photos with most specimens within this group. Air entrapment occurs most frequently between the two posts resulting in non-uniform cement layer and unstable stress distribution throughout the canal walls which compromised the bond strength of the post. (7,49) The practicality of using multiple posts with oval or flared canals has been discussed in some former studies although the results were disputing and not clear. (8,50)

The fabrication of the anatomic post through customization of the circular fibre post with resin composite all around the post to take the exact shape of the root canals gives also encouraging results. This might be attributed to the least cement layer thickness obtained within this post technique. In previous studies, the authors interpreted the high bond strength values of the relined group by the increased frictional retention, highlighting the effective retention of the relined fibre posts to the dentin through sliding friction against dentinal walls of root canals rather than true adhesion.(26,51) It is notable that even though the post technique showed lower cement thickness values than oval post technique, the latter revealed better bond strength values than relined post technique. This point needs further investigations on whether the resin composite surrounding the post had led to any changes in the stress distribution within the multiphase assembly of the post systems.

Concerning the results of the push out bond strength at different root levels regardless of post techniques, it has been concluded that the coronal and middle root levels showed statistically significant higher mean push out bond strength values than apical root level for all groups except the relined group where the coronal and middle were higher than the apical but with no statistical significant difference between the three root levels. This may be correlated to the decreased number of the dentinal tubules in the apical third resulting in reduced intratubular diffusion of composite resin luting cement at this area. This has been discussed in previous studies earlier in the literature.(34, 51) Some authors stated that the apical bonding is critical as well due to difficult accessibility and cleaning within these narrow diameters, correspondingly the presence of gutta percha remnants hinder the bonding capability at this region. [52,53] Besides, incomplete polymerization of resin luting cements may be a factor in reduction of the push out bond strength in deeper apical areas. [54]

It is important to mention that dual cure self-adhesive resin cement was used in this study for cementation of all post techniques. This was chosen due to its less technique sensitivity. Dual curing cement was selected as it is supposed to adequately polymerize in deeper areas of the post space that cannot be reached by light. However, it was stated that sometimes with the absence of light, some dual curing cements may not reach an adequate degree of polymerization.[54,55] It is worth mentioning that Rely X Unicem cement was introduced into the post space using the cement long narrow tip to reduce the tendency of air entrapment and introduction of bubbles or gaps confirming a high-quality void free cement film, although voids in the cement layer were noticed in some specimens especially with single and double circular post techniques.

It is of significance to state that the oval fiber post used in this study is made of quartz fiber and the circular posts are made of glass fiber. This might have presented a limitation to the present study. Similarily,Uzun et al [36] compared the oval quartz fiber with the circular glass fibers and reported higher bond strength to the oval posts. Other studies compared quartz fiber post with quartz circular post and revealed similar bond strengths in oval shaped canals.[10,21] On contrary,Some authors concluded insignificant differences among different fiber post types .[56]

The addition of thermal and mechanical loading as well as aging process might have given more clinical simulation to the present study which is considered one of the limitations of this study.

As the fibre posts have been popularly used nowadays, further studies should be conducted to assess the bond strength of different post techniques after artificial aging which might give more realistic results. The de-bonded posts must also be examined under magnification to determine the mode of failure of different post techniques.

CONCLUSIONS

Within the limitations of this in vitro study, the following may be concluded:

- The use of single circular post technique in oval or flared canals is not a good option for long term clinical service.

- Decreasing the cement thickness space around the post systems in oval canals will improve the push out bond strength of posts to dentinal walls of the root canals.

- The introduction of oval posts for restoration of endodontically treated teeth with oval and flared root canals gives promising results in push out bond strength tests.

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