Original Article

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Aging and thermocycling effects on adhesion of fiber posts to human radicular dentin

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Abstract

Aim: This in vitro study evaluated the effect of different aging periods and thermocycling on the adhesion of fiber posts to human dentin at different depths. **Methods:** Twenty teeth were cleaned, decoronated, and endodontically treated. After one week, root filling was removed and a 10-mm post space was prepared. Posts (RelyX™ Fiber size 2) were cemented with a self-adhesive resin cement (RelyX™ Unicem) and light cured. Specimens (n=4, each) were stored in 100% humidity (0 day, 7 days, 1 month, 3 months) or thermo-cycled (at 7 days, 10,000 cycles, 5-55C°, 30 s). Four 1-mm-thick sections were obtained from each tooth and a push-out test was performed and results compared. **Results:** There was a significant difference (ANOVA $p<0.05$) between the means of push-out test results (MPa ± SE) at different storage periods: 24 hours: 15.2 ± 1.4; 7 days: 16.8 ± 1.5; 1 month: 20.3 ± 1.8; and 3 months: 12.5±2.0. Shear strength was significantly different (Chi-square, $p<0.05$) at the different slice positions. Apical sections had an increase in strength at 7 days and 1 month, but without statistical significance. The coronal section increased significantly between 0 and 7 days. All sections had reduced strengths between 1 and 3 months, but only the apical sections decreased significantly (ANOVA, $p<0.05$). There was no significant difference in shear strength between thermally cycled and non-cycled samples (MPa/SE 16.7± 5.9, MPa/SE 16.0 ± 9.3)($p>0.05$). **Conclusions:** Long-term storage of test samples affected the bond strength of fiber posts to radicular dentin variably, and should be considered as part of in-vitro testing.

Keywords: adhesion, fiber post, push-out test, radicular dentin, storage, thermocycling.

Introduction

Damaged tooth structure get support and retention from various post materials and methods with emphasis on esthetic demands[1]. Many in vitro tests of fiber post material analyze dentin-cement-post system behavior under proposed clinical situations. These tests were reviewed and reasons for the variability of strength results were indicated[2-6]: 1. Tests were done on full-root samples (as pull-out and fracture compressive load), or root sections (as micro-push-out or hourglass- and rectangular stick-shaped microtensile testing); 2. As the method of force application differed, values of adhesion reported varied; 3. Pull-out of a whole post from full roots had highest values of bond strength, followed by push-out tests from root sections; 4. Failures and high standard deviations of strengths reduce the reliability of test values. A large number of premature failures (during specimen preparation) occur with hourglass and stick tensile tests; 5. Full root sample testing was dependent on the morphology of radicular dentin; 6. The push-out test of thin

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perpendicular root sections showed advantages over other testing methods: strength measurements were more consistent, stress distribution was more homogenous (finite element analysis), strength values were less variable, flaws were distributed uniformly and finely throughout the material (this is called a higher Weibull modulus), fewer premature failures were found (confined mainly to root samples not embedded in resin blocks), and finally, there was differentiation of regional differences in bond strength; 7. Moisture, heat and fatigue stresses interplay and reduce the longevity of fiber posts clinically, and were standardized conditions added to samples before testing. These were applied either to whole teeth (which best mimics the clinical situation), but other studies concluded from applying them to dentin powder, isolated dentin sections of coronal dentin, or unsealed samples with an enamel-bonded margin, or bovine teeth; 8. Variability also resulted because tests were applied to different cements, adhesives, posts, dentin substrates and irrigant materials.

The study reported here applies some of these clinical conditions to intact human roots that received fiber bonded posts and were tested by push-out tests with different storage periods and thermocycling. The null-hypothesis states that no difference will be detected after different aging periods and thermocycling of intact roots on the adhesion of fiber posts to radicular dentin at different root section locations.

Material and methods

Sample selection

Twenty, caries and crack-free human maxillary central incisors and canines with straight 14-mm-long roots and mature apices were selected. A single canal was verified by 2-angled radiographs.

Ethical approvals

This study was supported by grant no. 149/2009, by Jordan University of Science and Technology, Jordan. The study was independently reviewed and approved by the Research Committee, (Deanship of Research) and the Institutional Research Board (IRB), specialized in human-research ethics, (Faculty of medicine).

Sample preparation

Debris were cleaned and the intact teeth were disinfected (30 min, 3% sodium hypochlorite sonic bath; Sultan chemists, 300 Pro. Sonic, Branson Ultrasonics) and stored in thymol solution until the time of testing.

Root Canal Treatment

The crowns were removed 2 mm above the buccal cementoenamel junction (0.5 mm diamond wafering blade; Isomet, Buehler Ltd, Lake Bluff, IL, USA) under copious water cooling. A #15 K-type file was inserted until it could be seen at the apical foramen, and then 1 mm was subtracted from this length to determine the working length. Crown-down technique prepared canals for root canal filling (S1, S2, S3, F1, F2 and F3 ProTaper files on X-smart handpiece; Dentsply Maillefer, Switzerland). Irrigation (1 mL of 1% NaOCl solution; PD, Dentaires SA, Switzerland,) and File-Eze (18% EDTA, Ultradent, South Jordan, UT, USA,) were used between files. A final rinse (5 mL distilled water) and drying (ProTaper Paper Points, Ref A 022W; Dentsply Maillefer, Switzerland) were done, then AH26 resin sealer (Dentsply Deterey, Konstanz, Germany) was applied using a lentulo spiral onto the dry canal.

Cold lateral condensation technique was used to obturate the canals (gutta-percha cone and fine accessory points, ProTaper Gutta Percha Points, Dentsply Maillefer, Switzerland). The coronal part, 2 mm below the orifice, was cleaned and sealed (Cavit-G; 3 M ESPE, Seefeld, Germany). The root tips were immersed in saline solution in a closed container to ensure high humidity. The container was stored in an incubator at a 37°C to allow setting of the sealer for at least 7 days.

Post Space Preparation

Root filling was removed (Gates-Glidden, Gates, Dentsply Maillefer, Switzerland) and a 10-mm post space was prepared, leaving at least 3 mm of the root filling apically (universal burr, Size 2 drill, RelyX™ fiber post kit; t, 3M ESPE, Seefeld, Germany). Posts (RelyX™ Fiber size 2, 3M ESPE, Seefeld, Germany) were cleaned with alcohol, tried for the fit (binding was excluded) and protected from any further contamination. The post space was irrigated with normal saline and then 5 mL of distilled water. Canals were dried with paper points (ProTaper Paper Points, Dentsply Maillefer, Switzerland).

Cementation of the post

The self adhesive resin cement (RelyX™ Unicem, 3M ESPE, Seefeld, Germany,) was activated, mixed (15 s capsule mixer, Italy), and then applied into canal (Elongatin tips, 3M ESPE, Seefeld, Germany) according to the manufacturer's recommendation. The post was seated immediately, slightly twisted, and moderate pressure was applied to hold the post in its position while removing excess and during polymerization (600 mW/cm^2, 40 s through the post, 20 s cervical, buccal and lingual surfaces).

Aging and storage

Specimens (n=4, each) were either stored in 100% humidity for different periods (0 days, 7 days, 1 month, 3 months) or thermocycled after 1 week of storage (5-55C°, 10,000 cycles, 30-s soaking, 12-s intervals).

Sectioning

After the storage period, the teeth were mounted in molds of polyester resin (HM 190 unsaturated polyester resins, intermediate petrochemicals industries, Jordan) for the ease of handling and sectioning. The specimens were then sectioned in a Isomet sectioning machine (Buehler Ltd, Lake

Bluff, IL, USA) with a 0.5 mm diamond wafering blade under copious water cooling, and loss between each slice was measured to be 0.6 mm. Four 1-mm-thick sections were obtained from each tooth and identified as coronal (S1), sub-coronal (S2), epiapical (S3) and apical (S4) (Figure 1).

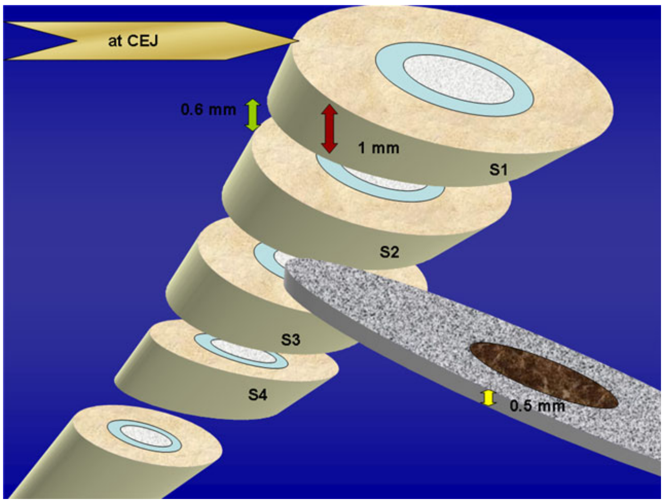

Fig. 1: Sectioning procedure followed at the cementoenamel junction and standardizing 4 sections: Coronal - S1, Subcoronal - S2, Epiapical - S3, and Apical - S4. The most apical portion of the post is not included.

Bond strength Test

A push-out test was performed in a (Universal Testing Machine, Jinan testing equipment corporation, PRC). The sample mounted on the testing machine on a table with a 3-mm-diameter central opening to allow the escape of the de-bonded post. An indenter with a diameter of 0.5 mm was used to apply the force on the post in an apico-coronal direction at a crosshead speed of 1 mm/min until the post was dislodged (Figure 2).

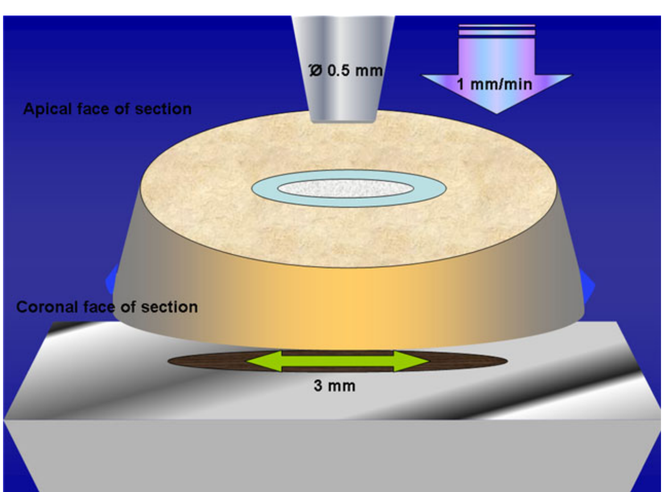

Fig. 2: Loading specimens for push-out test on the shear-strength universal testing machine.

Statistical analysis

The retentive strength of the post segment was expressed in MPa, by dividing the load at failure (Newton) by the interfacial area of the post fragment (SL). The latter, being the lateral surface of a truncated cone, was calculated by the formula: SL = ð (R+ r) .[(h2 (R - r) 2] 0.5, Where ð= 3. 14, R: coronal post radius, r: apical post radius and h: root slice thickness. The differences between groups were tested using ANOVA to compare means of tested groups. Chi square and Tukey's HSD test were used to test the results in terms of slice position ($p<0.05$).

Results

Effect of storage period

There was a significant difference between the means of push-out test results at different storage periods (ANOVA $p<0.05$) (Figure 3). Shear strength was significantly different at 1 and 3 months of storage (Tukey HSD, $p<0.05$). Immediate or baseline values were considered testing samples at baseline (24 hours of storage) and comparison with 1-week of storage showed that stored samples had a slight increase in test values (0 day: 15.2 ± 1.4; 7 day: 16.8 ± 1.5 MPa/SE). Then the strength increased reaching the maximum at 1 month (20.3 ± 1.8 MPa/SE), then reduced to its lowest value at three months (12.5±2.0 MPa/SE).

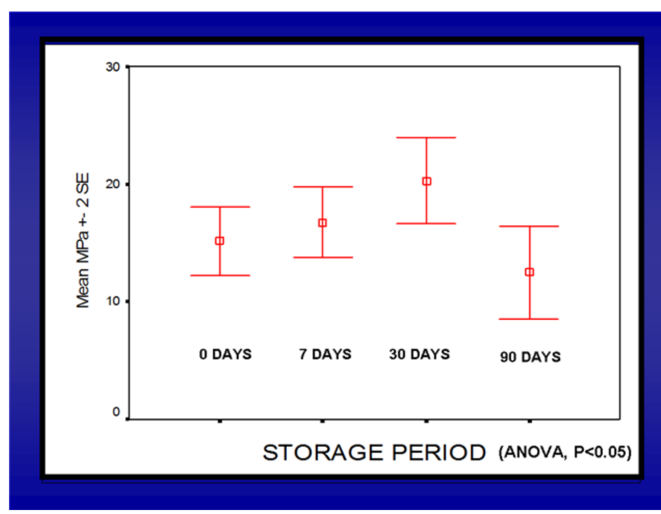

Fig. 3: Total Shear strength of all samples (MPa, Mean SE) per group, at different storage periods.

Effect of slice position

Shear strength was significantly different at different slice positions (Chi-square, $p<0.05$). Apical and epiapical sections had an increase in strength at 7 days and 1 month but without statistical significance. Coronal sections had a significant increase in strength between 0 and 7 days. All sections had reduced strengths between 1 and 3 months, but apical section decreased significantly between 1 and 3 months (ANOVA, $p<0.05$) (Table 1).

Effect of thermal cycling at 1 week

The number of cycles used here are 10,0000 and

Table 1 - Mean shear strength (MPa ±SD) for each section at different storage periods. (ANOVA**, $p<0.05$, ANOVA—,$p>0.05$, Tukey HSD*, $p<0.05$ between designated sections** with *, Tukey HSD—,$p>0.05$).

	0 day		7 day		1 month		3 months		total	
Section	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Coronal	9.2*	1.9	14.3	3.1	17.2	5.6	13.2	12.4	13.2*	6.8
Subcoronal	13.9	6.5	12.4*	4.2	16.4	6.0	9.5	7.4	13.3*	5.9
Epiapical	16.7	5.5	16.8	5.4	20.9	9.6	14.6	6.1	17.2*	6.5
Apical	20.8**	5.7	23.6**	4.9	26.8	4.5	11.9	5.7	20.7**	7.3
	ANOVA** Tukey HSD*		ANOVA** Tukey HSD*		ANOVA— Tukey HSD—		ANOVA— Tukey HSD—		ANOVA** Tukey HSD*	

performed over 10 days. There was no significant difference in shear strength between the two conditions for the whole samples (16.7± 5.9 and 16.0 ± 9.3 MPa/SE)($p>0.05$). Subcoronal and apical sections had a non-significant increase, while coronal and epiapical sections had a non-significant decrease of stress values (Table 2).

Table 2 - Mean shear strength (MPa ± SD) for each section at 1 week, comparing before and after thermocycling (ANOVA**, $p<0.05$, ANOVA—,$p>0.05$, Tukey HSD*, $p<0.05$ between designated sections, Tukey HSD-,$p>0.05$).

	7 days		7 days with thermocycling	
Section	Mean	SD	Mean	SD
Coronal	14.3	3.1	11.1	7.6
Subcoronal	12.4*	4.2	14.5	6.4
Epiapical	16.8	5.4	13.3	6.2
Apical	23.6*	4.9	25.0	11.9
	ANOVA** Tukey HSD*		ANOVA— Tukey HSD—	

Discussion

A five-year survival rates for fiber posts are considered satisfactory[7-8] and depend on the location of the tooth restored, type of final restoration, presence of proximal contacts from adjacent teeth, presence of a ferrule, remaining coronal structure and occlusal loads[9-11]. Nevertheless, the failure mode is usually a restorable de-bonding of resin bonded fiber posts, and can be enhanced by using various pretreatment procedures[12].

In vitro studies have tried to test dentin bonding behavior from tests applied to dentin sections and not endodontically and post-restored intact teeth. Testing the radicular dentin-bond-cement-post system could be proposed to have different results than testing sections or non-sealed dentin surfaces[2-6]. Even in this closed system, more standardization is needed.

This study standardized the taper of endodontic preparation, endodontic filling, post space preparation, irrigation, cement, post placement, coronal seal, and light curing for all study samples. Test variables - storage and thermocycling - have been subjected to intact and sealed roots. Then, resin-block addition, around these root samples, aimed to only facilitate the sectioning procedure. Standardizing the cement in this study, and using only RelyX Unicem, was essential. It had similar flexural strength to the conventional resin cements. Even higher strength and modulus of elasticity were evident when light cured. Its low initial pH is characterized by a more rapid rise to neutrality than other cements, regardless to the curing method[11]. Although criticized, not being able to effectively remove the thick smear layer[12], the cement formed sporadic resin tags and hybrid layers, and it had the highest bond strengths when compared to other conventional cements[6,13]. In addition, this higher chemical interaction between the cement and hydroxyapatite caused no displacement of the resin components across the dentin tubules[12]. Its strength was not affected if present in thicker cement layers[13]. And when test samples were examined for failure modes, it was the only one to show an adhesive-cohesive mixed fracture[14-16].

The effect of storage

Storage of bonded restorations caused deterioration by infusion of fluid into its matrix, from periodontioum, coronal and apical ends of the restorations. If no peripheral failure is observed in restorations, this leakage is confined to fluids and not to macromolecules and microbial products. Later, a progressive disintegration of the fibrilar network of the collagen occurs in hybrid layer. Matrix metalloproteinase (MMPs) bind to dentin matrix and become activated or come from pulp tissue, odontoblasts, saliva or microbial macro-molecules[2-6]. Further expression of their activity is produced by acidic challenges to dentin tissue during bonding procedures[17]. Another effect of fluid ingression during storage is the plasticizing of resin bond and cement materials. However, a study, using multiple cements, concluded that 3-month storage of intact samples in deionized water had no influence on the hardness of 3 common post-cements, with the exception of RelyX Unicem. It had a significant increase in the hardness values after storage[18].

Comparing strength values at different slice depth

It could be proposed that the restored canal system behaves differently at different depths from the cementoenamel. One difference between layers is the adaptation of the post to canal walls, increasing adhesion forces, and friction, while reducing the low cohesive strength, fluid ingression and flaws relevant to the cement layer[19]. Apical portions expected to be closer and could be matched in size with the post, by custom-post preparation burs. If a close fit is produced, by post relining for example, higher retention values were obtained than non-relined post, in all thirds, along with disappearance of differences among various depths[19]. When precise fitting was reached, RelyX Unicem had similar or higher strength values, compared with other cements, after water storage and thermocycling.

In oversized post space, it was second after Build-It, SuperBond and Panavia[13,20-21], in comparison with 3 other different cements with thermocycling only. Fracture modes were shown by other cements to be mainly adhesive at the post surface or cohesive for precisely fitting posts and to occur between post and composite, except for RelyX Unicem with cohesive fractures, for the oversized spaces. Finite element model found that indirect and direct restorations produced both strain and stress, off the scale in the middle third of the buccal aspect of the root surface. While minimum values were noticed at the level of both the apical portion of the post and the root apex[22]. In vitro studies not including the previous clinical conditions have shown the contrary.

Cervical (coronal sections) regions have higher strength values than middle and apical thirds, respectively[2-6]. The preference of light curing to easily accessible cervical regions could be one reason for this result. RelyX Unicem showed the same result in a previous study[23]. The reason could have been the amount of non-homogenous cement that was less in the cervical than in the middle and apical levels. The application tip used in this study significantly reduced these failures, but they were still more predominant in apical areas[24].

Another problem was that the brush used to coat adhesives accessed cervical regions with more material, leading to better resin tag morphologies[25]. Using the unique application tip, then inserting the post in it, excluded the formation of air inhibited layers in the cement. Finally, contamination of apical regions with remnants of sealing material is more prominent in apical regions[26]. This final limitation was excluded from this study as the last 1.4 mm of the post was not included in the sections. This study was persistent with the results of the first group; apical sections were stronger than other sections that gradually decreased up to the coronal. The apical even benefitted to some extent from thermocycling, in the same way as observed in a previous study[16], but was significantly affected by the storage, leading it to comply more with the second group[27]. Studies that have shown a thermocycling effect used a larger number of cycles, 40,000, and were subjected to exposed sections, not intact teeth[28].

Within the limitations of this study, it was observed that intact and sealed roots produced different fiber post bonding results in comparison with other studies applying these conditions to dentin sections, powder or un-sealed restorations. Such variation should be taken into account when planning in vitro studies which test and conclude on the behavior of the radicular dentin-cement-post system on the long-term and at different regions within the root.

Acknowledgements

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