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Wael Raafat
Master Candidate, Department of Fixed Prosthodontics, Faculty of Dentistry, Cairo University, Egypt

Lamia Kheiralla
Professor, Department of Fixed Prosthodontics, Faculty of Dentistry, Cairo University, Egypt

Omnia Nabil
Lecturer, Department of Fixed Prosthodontics, Faculty of Dentistry, Cairo University, Egypt

Corresponding Author:
Wael Raafat
Master Candidate, Department of Fixed Prosthodontics, Faculty of Dentistry, Cairo University, Egypt

Effect of laser surface treatment of glass fiber posts on their bond strength to intra-radicular dentin at different root levels: An *in-vitro* study

Wael Raafat, Lamia Kheiralla and Omnia Nabil

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Abstract
Statement of the problem: Despite the fact that adhesive luting is recommended for teeth rehabilitation with glass fiber posts, the most common failure of these restorations is debonding of the glass fiber posts.
Aim: To evaluate the effect of laser surface treatment of glass fiber posts on their bond strength to intra-radicular dentin at different root levels.
Materials and Methods: Twenty extracted single-rooted permanent human teeth were decoronated and endodontically treated. Post space of 10 mm length was prepared to receive glass fiber post. Teeth were randomly divided into 2 groups based on the surface treatment applied to the post surface as follows;
Group A (Control): post surface received conventional silane treatment,
Group B: Er:YAG laser was applied to the post surface followed by silane application. Prepared post spaces of all teeth were irrigated using standard irrigation protocol then dried and self-adhesive resin cement was used for posts cementation. For push-out bond strength evaluation, three slices for each sample were prepared, and the test was performed using a universal testing machine at a crosshead speed of 1 mm/min.
Results: Statistical analysis showed that group B provided significantly higher bond strength values compared to group A.
When different root sections were compared in each group: group A showed a significantly higher bond strength values in the middle and apical sections compared to cervical ($p<0.05$), while no significant difference was noticed between all sections in group B ($p>0.05$). In addition, the
Comparison between both groups in each section revealed that: group B showed significantly higher bond strength values in cervical and apical sections than group A. While in the middle section, group B recorded a non-significant increase in the bond strength compared to group A.
Conclusion: Er: YAG laser treatment for the post surface can be used as an alternative to conventional silane treatment to enhance its bonding to intra-radicular dentin.

Keywords: Er: YAG laser, Glass fiber post, push-out bond strength test, Surface treatment, resin cement

Introduction

Endodontically treated teeth are weaker and more prone to fracture than vital teeth, this may be due to changes in dental tissue composition and physical characteristics after root canal treatment [1]. In the case of severely damaged teeth, an endodontic post is required to restore and reinforce the tooth [2].

Different types of posts are used to restore the teeth after root canal treatment, including cast ceramic and metal posts, and prefabricated metal and fiber posts. Fiber-reinforced posts are preferable as their modulus of elasticity which is closer to that of the dentine, allowing uniform distribution of stresses to the remaining root structure rather than concentrating them, resulting in a more favorable failure mode [3].

Luting a post inside the root canal is a technically challenging procedure, and adhesive techniques are recommended with appropriate bonding protocols for post-placement to preserve the maximum amount of dentin, enhance post retention and resistance to root fracture, and reduce microleakage [4].

The smooth surface of untreated fiber posts as well as their unreacted resin component weakens its mechanical interlocking with resin cement.

Therefore, multiple surface treatments like hydrofluoric acid etching, sandblasting, tribo-chemical silicoating, and hydrogen peroxide application were suggested to enhance the micro-mechanical interlocking due to their ability for resin coating removal and exposure of the impeded fibers. This facilitates chemical bonding when silane is applied [5]. However, none of the pretreatment methods are effective enough to recommend their use in daily practice [6].

Laser has been introduced as an alternative method for post surface treatment to increase the roughness of glass fiber post surface and remove the resin coating allowing chemical interaction with the exposed glass fibers when silane coupling agent is applied [7]. However, the actual effect of laser application and its correct parameters is still controversy and needs more research. So, this study aimed to evaluate how laser surface treatment of glass fiber posts affected their bond strength to intra-radicular dentin at different root levels.

The first null hypothesis was; laser treatment for post surface will not enhance its bonding to intra-radicular dentin compared to conventional treatment. The second null hypothesis was; no difference in bond strength will appear between different root levels.

Materials and Methods

Ethical Approval

The study was approved by research ethics committee at Faculty of Dentistry Cairo University with an approval number of 19-12-4.

Sample size

According to the results of Gomes, Karla GF, *et al*. in which the (mean ± SD) value for the first and second groups were (2.626±1.01) and (1.358±0.45) and by adopting 5% alpha (α) level, 20% beta (β) level i.e. power=80% and 1.62 effect size (d); the predicted sample size (n) was found to be a minimum of (8) per group. Sample size calculation was performed using G*Power version 3.1.9.4.

Teeth preparation

Twenty single-rooted permanent human teeth extracted for orthodontic or periodontal reasons were selected from outpatient clinic at Faculty of Dentistry Cairo University and patients were notified with the study aim and teeth inclusion in the research.

The selected teeth were used within a month of extraction and stored in a distilled water according to the International Organization for Standardization recommendations [8]. Each tooth was radiographically checked and decoronated using a low speed diamond disc under constant copious water cooling at junction between enamel and cementum maintaining root with average length of (15 mm ±1). Buccolingual and mesiodistal dimensions of each root were checked using a digital caliper [9].

Root canal treatment for samples

Instrumentation was performed with a crown-down technique using rotary nickel titanium instruments (Revo-S, MICRO-MEGA, China), keeping master apical file at size 45 stainless steel K-file (Mani, Tochigi, Japan). Canals were obturated with cold lateral compaction technique and epoxy resin-based sealer (ADSEAL, META BIOMED CO., LTD, Korea). Roots were stored 24 hours in distilled water [10]. Roots were then fixed vertically in the center of the epoxy resin block using a vertical holding device (Dentsply Parallelometer Surveyor, USA) [11].

Post-space preparation

Preparation of 10 mm post space was done by a parallel milling unit (Bredent BF2, USA) using the corresponding drill (special tapered 1.50 mm drill) assigned by the manufacturer for the post used (Size #3 FibreKleer 4x post, Pentron, USA) leaving (5 mm ±1) of gutta-percha to preserve apical seal as shown in figure (1) [10].

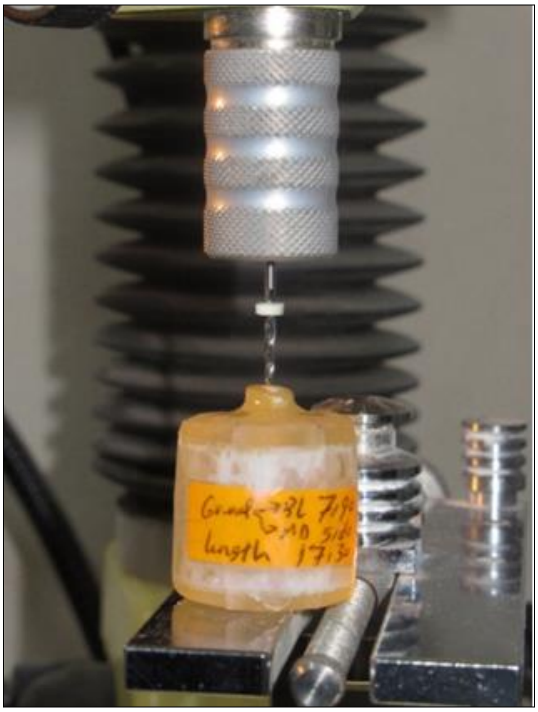

Fig 1: Parallel milling unit with mounted drill for post space preparation

Surface treatments

Samples were assigned into 2 different groups (n=10) based on the treatment applied to glass fiber posts before bonding as follows:

Surface treatment in Group (A) (Control group)

Post surface was cleaned using alcohol swab, dried with air, then silane was applied to the post surface with a special brush and allowed to evaporate for 1 minute as seen in figure (2) [12].

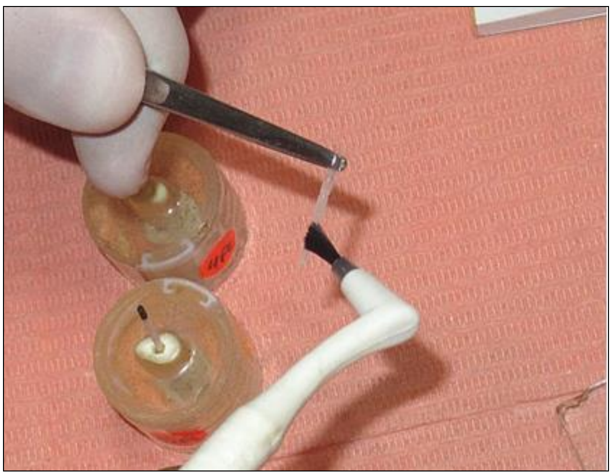

Fig 2: Silane application to the post surface with a special brush

Surface treatment in Group (B) (Intervention group)

Post surface was treated with Er:YAG laser (LightWalker; Fotona, Ljubljana, Slovenia) in non-contact pulsating mode using cylindrical fiber tip (1 mm diameter and 8 mm length) under water cooling for 60 seconds (15 seconds per side) as shown in figure (3). This was followed by silane application to the post surface. The parameters used were: 10 Hz repetition rate, 150 mJ energy, 1.5 W output power, and pulse duration of 100 µs [12–15].

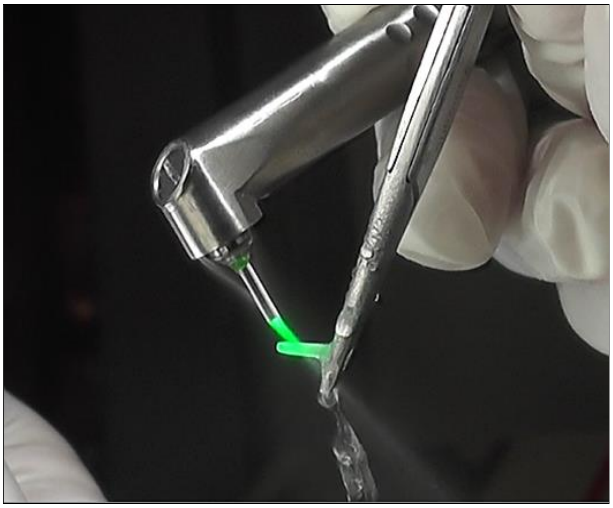

Fig 3: Laser application to the post surface

Post cementation

Prior to cementation, post spaces were irrigated using standard irrigation protocol (5.25% NaOCl followed by distilled water, then 17% EDTA, and again distilled water as a final flush) [16, 17], then dried and the posts were cemented using dual-cured self-adhesive resin cement, and light-cured [18, 19].

Preparation for push-out bond strength test

Three 1.5 mm thick slices were attained from each root sample by cutting machine under water cooling (IsoMet 4000 microsaw, Buehler, USA) to represent various root levels (cervical, middle, apical) and their thickness was confirmed using a digital caliper. The push-out bond strength test was done using a universal testing machine at a cross head speed of 1 mm/min in an apico-coronal direction as shown in figure (4) [16, 19].

The maximum failure load was determined by using the greatest recorded value, and the area under load was calculated using the following formula:

Area = circumference of restoration × thickness.

The push-out bond strength in MPa was calculated from force (N) divided by area in mm^2.

Statistical Analysis

Graph Pad Prism®, SPSS 20® and Microsoft Excel 2016 were used to perform the statistical analysis. Data was displayed as mean and standard deviation. Shapiro Wilk and Kolmogorov-Smirnov tests were used to check the normality of Data and comparison between groups & between three sections were performed by ANOVA test followed by Tukey`s post hoc test for multiple comparisons.

Fig 4: Push-out bond strength test

Results

Group A

In group A, in cervical section the mean ± standard deviation of push-out strength was 10.8 ± 2.62 MPa, in middle section was 14.54 ± 2.91 MPa, in apical section was 12.08 ± 2.46 MPa, while in overall was 12.47 ± 2.17 MPa.

Comparison between different sections revealed that there was statistically significant difference between them as ($p<0.05$). Middle section showed significantly the highest bond strength followed by apical section while cervical section showed significantly the lowest bond strength.

Group B

In group B, in cervical section the mean ± standard deviation of push-out strength was 13.98 ± 4.94 MPa, in middle section was 15.5 ± 3.15 MPa, in apical section was 15.8 ± 3.2 MPa, while in overall was 15.09 ± 3.81 MPa.

Comparison between different sections revealed no statistically significant difference between them as ($p>0.05$). However, apical section showed higher bond strength values followed by middle section, then cervical section.

Comparison between both groups

Group B showed significantly higher bond strength values compared to group A in cervical and apical sections ($p<0.05$), while in middle section, group B showed higher bond strength values than group A but the difference was statistically insignificant ($p>0.05$), as presented in table (1) and figure (5).

Table 1: Mean & standard deviation of push-out strength (MPa) in both groups at cervical, middle & apical sections and comparison between them

.	Cervical		Middle		Apical		Overall	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
A	10.80	2.62	14.54	2.91	12.08	2.46	12.47	2.17
B	13.98	4.94	15.50	3.15	15.80	3.20	15.09	3.81
P-value	0.006*		0.76		0.003*		0.02*	

P: probability level which is significant at $p \leq 0.05$

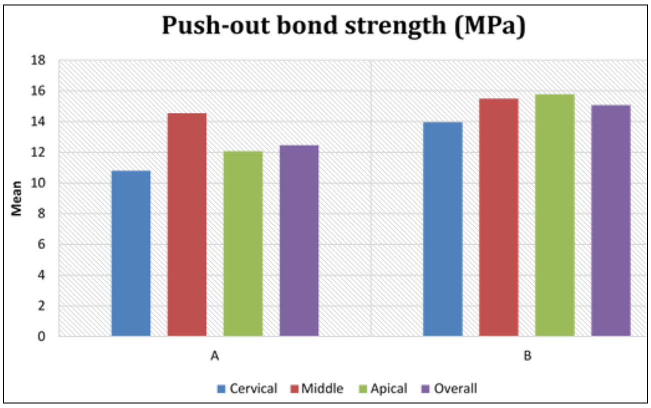

Fig 5: Column chart showing mean of push-out strength (MPa) in both groups at cervical, middle & apical sections and comparison between them

Discussion

Severely destructed root canal treated teeth showed a weak dentin structure which make them more susceptible to structure loss and fracture [1]. So, these teeth need to be restored with a root canal post for retention of the core and long-term clinical success [2]. However, most reported failures are due to loss of post retention [20].

After root canal treatment, root samples were fixed vertically in epoxy resin block to facilitate handling and treatment procedures, this step was done with the help of vertical holding device to standardize the position of each sample in a vertical direction within the block [11].

Post spaces were then prepared using parallel milling unit to make sure that preparation done with the teeth long axis and to standardize the method. The same drill with the same corresponding post size was used to standardize the bonding surface area. A rubber stopper was attached to the drill to ensure an accurate 10 mm drilling depth in all root samples [10, 21].

After preparation of the post space, a thick smear layer was formed and it was thought to affect post adhesion to intra-radicular dentin. So, different methods were used to eliminate the smear layer, and clean the prepared post space before post cementation to improve the micromechanical interlocking and resin penetration into dentinal tubules, hence improving the bond strength [22].

5.25% NaOCl was used in this study for its ability to clear the organic component of smear layer, hence increasing the monomer penetration into the dentinal tubules. This was followed by irrigation with distilled water as a neutralizing agent to compensate the effect of NaOCl, and to remove the residual oxygen free radicals that inhibit interfacial polymerization of resin cement. 17% EDTA solution was then utilized for eradication of the smear layer's inorganic part, and to open the dentinal tubules, followed by final flush with distilled water to remove the residual EDTA, that might cause sporadic erosion and dissolution of dentin and to avoid precipitate formation [12, 16, 17].

Different post types can be used to restore root canal treated teeth. Glass fiber post was used in this study due to enhanced esthetics, time-efficiency and its modulus of elasticity which approximates that of dentin, this allow preferable distribution of stresses and decrease the incidence of root fracture [3, 6, 23]. A translucent post was used to enhance the transmission of light within root canal and be certain that the resin cement had completely polymerized. Posts used were with the same diameter and placed into the same depth inside canals to standardize the bonding surface area [7].

The post surface don't have the ability to react with monomers of the resin cements due to the polymer matrix covering its surface. Also, uniform and smooth surface of the post limit proper mechanical interlocking with composite resin [24]. Different methods were used to enhance the post bonding to resin cement through changing of the surface energy of the post and enhancing wettability by developing a rough surface and exposing fibers, hence increasing the area available for chemical bonding between post and resin cement by silane application [5].

In our study, ethanol was used as the manufacturer recommended to clean the post surface from any contaminations, that may affect its bonding with luting cement. Uniform layer of silane was then applied to the post surface to allow better chemical bonding with the luting cement [12, 25, 26].

Er:YAG laser was also used to treat the post surface. It can be absorbed by hydroxyl groups in the post, causing ablation of the organic matrix, exposure of the fibers and increasing the surface roughness [7]. The post surface was treated with the following laser parameters (output power of 1.5 W, repetition rate of 10 Hz, 150 mJ energy, 100 µs pulse duration, under water cooling for 60 seconds) [12]. A 1.5-watt power was used as it has the ability to clear the resin coating without damaging the fibers, hence allow chemical bonding between silane and exposed fibers [15]. On the other hand, higher powers induce more heat that may destroy fibers, endanger the post integrity and decrease its bonding ability due to the released free radicals and methacrylate groups. This will cause physical damage to the post with negative effects on its chemical composition [27].

Self-adhesive cement was used for post cementation. It is more preferable than etch and rinse adhesive cement due to its low viscosity and simple application procedures which eliminate the need for tooth pretreatment. Its acid monomer component, help simultaneous demineralization and infiltration of tooth substrate creating micromechanical retention [28]. In addition, it has the ability to form a proper hybrid layer, even in the presence of smear layer. This in turn leads to improvement in the bond strength [29]. This cement is also dual-cured fulfilling the following advantages: low polymerization stress, high bond strength, compatibility with dry and wet dentin, and complete polymerization in deeper portions of the root which are inaccessible to light [30].

Different methods are used to test the posts' retention including shear, tensile, pull-out, and push-out tests. Tensile test can't be utilized to test intracanal fillings on account of higher rate of premature bond failures [31]. Push-out test is preferred and provides better results. So, in our study, it was selected to evaluate the bond strength of adhesively luted posts due to the following advantages: uniform load distribution, fracture occurs parallel to bonding interface, no premature failures, lower data variability, easy specimen preparation and test performing, and finally bonding at different root levels can be assessed. In addition, it simulates the clinical situation, so it is considered to be the most reliable test method [32].

According to our study results, Er: YAG laser irradiation of the post surfaces in group B had remarkably enhanced their bonding to intra-radicular dentin compared to group A with only silane application. So, the first null hypothesis was rejected.

These findings are in line with the results of many studies (Sipahi *et al*.; Gorus and Uner; Subramani *et al.*) [9, 12, 13] who compared the bond strength after different post surface pretreatments and reported improvement in the bond strength to root dentin following Er:YAG laser irradiation. On the contrary, Tuncdemir *et al*. [33] compared different post surface treatments and reported no improvement in the bond strength following posts irradiation with laser. They attributed this to the resin matrix dissolution of the used quartz posts after laser application which led to lower bond strength.

Furthermore, Gomes *et al*. [34] investigated the effect of different laser types used to treat the glass fiber posts including Er:YAG laser and revealed that the bond strength between the posts that were exposed to the laser radiation and the root dentin was comparable to that of the posts received only silane treatment. These variations might be explained by a number of elements, such as the laser parameters and post composition.

When different root levels were compared in each group separately regarding their bond strength, group A exhibited a significantly higher middle root level bond strength than cervical, while group B showed statistically no significant difference in the bond strength between different root levels. So, the second null hypothesis was partially rejected.

Considering the analysis of combined root sections and groups, our findings demonstrated that both groups reported the lowest bond strength in the cervical section. This might be attributed to the misfit between post and walls in the coronal region that leads to increase in the cement thickness which in turn, increase stresses in the weak cement layer due to polymerization shrinkage. Consequently, this will decrease the bond strength and result in bonding failure in the cervical third [35]. However, laser application in group B significantly enhanced the bond strength in the cervical section compared to group A. This is consistent with Subramani *et al.* [9]; Gorus and Uner [12] who reported improvement in the bond strength at cervical section following laser application to the post surface.

Regarding middle section, our results showed that the middle section had high bond strength values compared to apical and cervical sections in both groups with no significant difference between group A and group B. This could be related to the intimate contact between the post and root canal walls in the middle portion that allow for a thinner uniform cement layer and increase the bond strength [35]. These findings are in accordance with Hamdy [36] and Samimi *et al.* [37] who evaluated the push-out bond strength at different root levels and reported a significantly higher bond strength values at the middle third, followed by the apical, with cervical third being the lowest in bond strength.

Concerning the apical section, the results of this study demonstrated greater bond strength values in the apical section than cervical in both tested groups. This might be due to the post's close contact with the dentin walls in the apical third, which contribute to the formation of locking areas and improve both mechanical retention and adhesive bonding. In addition, the manufacturer claimed that the embedded glass fibers in the utilized posts had a role in transmitting light energy from the cervical to its most apical portions, which may have aided in complete polymerization of the adhesive system [38].

Furthermore, the bond strength in apical section was remarkably enhanced in group B upon laser application compared to group A. This could be explained by the post's reduced diameter apically, which allow more epoxy resin to be removed and glass fibers to be exposed, hence promoting micromechanical retention and resin cement infiltration [39].

These findings agree with that of Jha and Jha [38] who investigated the impact of various dentin regions on the post retention within the root canal and reported that the best bond strength was obtained with the apical sections. They explained this by noting that the amount of solid dentin and not the density of dentinal tubules appears to be more closely connected to the bonding to intra-radicular dentin as the tubule density decreases from the cervical to the apical thirds.

Finally, Er:YAG laser surface treatment of glass fiber post proved its efficiency in enhancing the bond strength which is expected to directly influence the chances of success of fiber posts and accordingly enhance the long-term survival of root canal treated teeth, this open the field for future clinical researches.

Conclusions

Within the limitations of this study, the following could be concluded

1. Er: YAG laser treatment for the post surface can enhance its bond strength to intra-radicular dentin at different root thirds.
2. Upon laser treatment, the bond strength of the post to intra-radicular dentin was high at cervical, middle and apical root thirds with no significant difference between them.
3. Upon conventional treatment, the bond strength was significantly improved at the middle third compared to cervical and apical thirds.

Recommendations

- Evaluation of the bond strength after thermo-mechanical aging.
- Clinical trials are required to verify the findings of this study.
- Evaluation of the fracture strength of post-crown restorations following laser irradiation.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper

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