THE EFFECT OF DIFFERENT SURFACE TREATMENTS ON THE PUSH-OUT BOND STRENGTH OF CAD/CAM MILLED ZIRCONIA POSTS (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Badly destructed teeth receiving root canal treatment is a main indication for post and core foundation. Zirconia posts were also a good treatment option as they combine strength and esthetics. Different methods were made to try to enhance the bonding capability of zirconia to dentinal walls.
AIM OF THE STUDY: The aim of the present study was to evaluate the effect of different surface treatments on the bond strength of zirconia to the dentinal walls.
MATERIALS AND METHODS: Thirty endodontically treated human maxillary central teeth were used. The specimens were randomly divided into three groups according to the surface treatment the post received. Group (I) tribochemical silica coating, Group (II) CO_2 laser irradiation and Group (III) Er.Cr:YSGG laser irradiation. Push-out bond strength was tested using a universal testing machine at a cross head speed of 0.5mm/min until post debonding occurred then the bond strength values were calculated.
RESULTS: There was a statistically significant difference in the debonding load (Mpa) among the three studied groups ($p < 0.05$). Group I had a mean of debonding load of (12.20±0.90 MPa) and (10.20±0.74 MPa) for group II while the mean of debonding load for Group III was (6.22±1.17 MPa)
CONCLUSION: Tribochemical silica coating was found to be the best surface treatment method for the zirconia ceramic surface when compared to CO_2 and Er.Cr:YSGG laser irradiation and would serve as a successful surface treatment option for zirconia ceramic prior to bonding.

KEYWORDS: Zirconia posts, Silica coating, Laser irradiation.
RUNNING TITLE: Surface treatments effects on bonding of zirconia posts.

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INTRODUCTION

Teeth that previously received root canal treatment often are in need to be restored with crowns. Absence of sufficient coronal tooth structure to support the final restoration is a main indication for post and core foundation to gain intraradicular retention and support to the coronal restoration (1,2). Root fractures are the most serious type of failure encountered in post-restored teeth if they have inadequate resistance to rotational forces. In order to decrease incidence or root fracture, posts should have an elastic modulus similar to that of dentin (3) and it is important for the post to be firmly cemented to provide maximum retention for the restoration and adequate support for the remaining tooth structure (1).
Posts made of tooth-colored material were introduced, and had to have two main clinical requirements; a high flexural strength and an elasticity modulus close to that of dentin (4).
Due to their low modulus of elasticity and relatively low flexural strength, glass Fiber posts were found to bend generating stresses at the post/resin cement interface causing subsequent debonding (5).
Due to favorable esthetic and mechanical properties, endodontic posts made of partially stabilized zirconia ceramic have also been described. Using partially stabilized zirconia posts were found to be biocompatible and at the same time enabled clinicians to use translucent all ceramic coronal restorations with no fear of displaying the underlying metal post color, in addition to the chemical stability of zirconia (6, 7).
One factor that can improve the resistance to fracture of teeth restored with zirconia posts is adhesive cementation. The use of resin cements for cementation renders the root less prone to fracture under masticatory loads achieving the monoblock concept; in which the root along with the post and resin cement act as a one unit minimizing the load per unit area being subjected on the tooth and preserving the dental structure (8).
Different mechanical and chemical pre-treatments for the post surface have been recommended to improve the bonding effectiveness of composite cement to zirconia by inducing surface alterations and micro roughness that can enhance further bonding to the ceramic surface (9).
This study evaluated the effect of surface treatment by tribochemical silica coating, CO_2 laser and Er.Cr.YSGG laser irradiation on the push-out bond strength of CAD/CAM milled zirconia posts. The null hypothesis proposed was that

there were no differences regarding the bond strength between the three different surface treatments.

MATERIALS AND METHODS

• Ethical considerations

The current study has been conducted after being approved by the Scientific Research Ethics Committee, Alexandria University.

All teeth were extracted due to severe mobility or lack of restorability and collected from the oral and maxillofacial surgery department, Faculty of dentistry, Alexandria University.

• Sample size estimation

The minimal sample size was calculated based on a study aimed to evaluate the influence of post surface treatment by a zirconia primer on the push-out bond strength of adhesively luted zirconia posts to root dentin. (10)

Thirty freshly extracted human maxillary central teeth were used. The crowns of each tooth were removed two millimeters above the level of the cement–enamel junction. Root canal systems were instrumented till size (40) apical preparation according to the conventional step back technique till the full working length of the canal and then obturated by cold lateral compaction. The root canal of each tooth was enlarged by post drills (Glassix,H.Nordin sa, Chailly–Montreaux, Switzerland) mounted on a low speed contra angled handpiece connected to a micro motor. The drills were used in order till reaching size #4 which was used as a final drill for shaping the post space. Irrigation by 1% NaOCl solution was used during drilling. The post preparation was terminated at 2/3 of the root length leaving approximately 4-5 mm of gutta-percha sealing the apical third. The root length was measured from the level of (CEJ) till the anatomical apex of the root then, the glass fiber post (Glassix,H.Nordin sa, Switzerland) size 4 was inserted into the prepared space till reaching the full prepared length and to ensure good fitting to the canal walls.

One glass fiber post was sprayed by scan spray (Renfert,GmbH, Germany) which was further scanned by an extra oral scanner (Kavo Arctica Scan, KaVo Dental GmbH, Biberach, Germany) to achieve standardization to all zirconia posts dimensions which were milled.

Thirty zirconia posts were milled using milling machine (Everest engine) and ZS blanks (KaVo Dental GmbH, Biberach, Germany) having the same dimensions and size of the fiber post. They were re-inserted into the canal to check their fit into the prepared space and x-rays were taken to ensure adequate post length. All posts were cleaned by soaking in 70% ethanol and cleaned in an ultrasonic bath. The posts were further divided into 3 groups according to the method of surface treatment each group received; each group consisted of 10 zirconia posts. During the procedure of surface treatment all posts were fixed onto a specially designed mandrel for the posts to be snugly fitted and secured by means of sticky wax to avoid eccentric rotation of the posts. The mandrel was mounted on a straight handpiece connected to a micromotor adjusted at a speed of 130 RPM regardless the type of surface treatment carried out (10).

Group (I): Posts were subjected to tribochemical silica coating using 30-µm silica-modified Al_2O_3 particles (Rocatec™ Soft, 3 M Espe, Seefeld, Germany) at a pressure of 2.5 bars at a perpendicular distance of 10 mm for 10 seconds then BIS-Silane was applied in a thin layer using a micro-brush and left to react then dried with oil and water free air. During the procedure, a Ni-Ti wire was cut and part of it was cut and fixed onto the tip of air-abrasion hand piece to maintain a constant distance from the rotating post with perpendicular hand movements 10 times back and forth along the post length. Fig. (1-a)

Group (II): Posts were be subjected to CO_2 laser irradiation (Smart US20D, Deka, Florence, Italy) in a pulse mode, at a wavelength of 10.6 µm with a pulse repetition rate of 100 Hz, pulse duration of 160 ms, output power of 3W for 50 seconds by laser and air spray (11-12). Fig. (1-b)

Group (III): Posts were subjected to Er.Cr:YSGG laser irradiation (Waterlase; Biolase Technology, San Clemente, CA, USA) in a pulse mode and at a wavelength of 2780 nm, pulse repetition rate of 50 Hz, pulse duration of 140ms, output power 3W, air/water ratio of 50/1 respectively and at a distance of 1mm for 50 seconds. The MZ8 tip with a diameter of 800- µm was used to deliver the laser beam to the post surface. The previous parameters were used according to the previous study by Zanjani (13). Similarly, the hand piece was moved in a back and forth movement 10 times along the length of the post. Fig. (1-c)

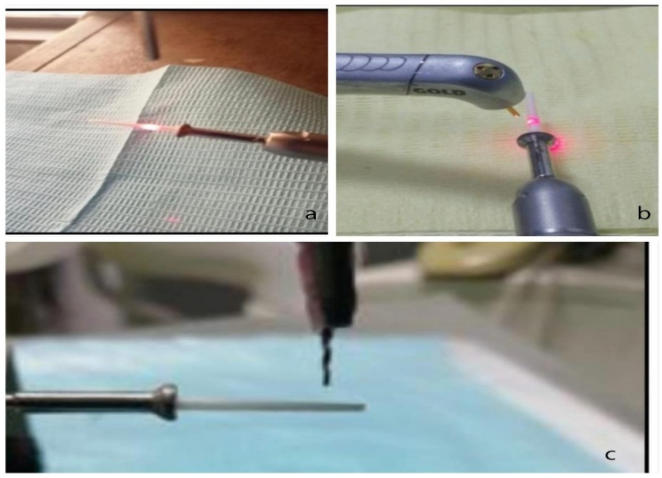

Fig. (1): Showing the post mounted on a straight handpiece ready for silica coating.

Each root was placed inside an acrylic block to be retained in position during cementation using a specially designed copper mould.

Before cementation of the posts, the root canals were thoroughly irrigated by EDTA solution and finally saline to ensure the best outcome for smear layer elimination that resulted from drilling, and then they were dried by paper points. Panavia F2.0 resin cement system (Kuraray noritake dental Inc, Osaka, Japan) was used for cementation of all posts into the canals according to the manufacturer's instructions.

Equal amounts of paste A and paste B were dispensed on a mixing paper pad, mixed and inserted into the canal using a lentulo spiral, the treated posts were coated with the cement then inserted in the canal under static load device till excess cement was extruded and cured for 5 seconds the partially set excess cement was wiped away by a plastic filling instrument. Oxyguard was applied on the cervical portion of the tooth then light cured for 40 sec on top and on each side of the root.

Each specimen was further sectioned using a diamond disk 0.6 mm thickness mounted on a microsaw (IsoMet 4000 Buehler USA) at speed of 2500 rpm and feeding rate 10 mm/min under water cooling. 2mm thick slices of apical-root portion for assessment of push out bond strength. Three sections were obtained from each specimen one apical, one middle and one coronal, each section was marked on its coronal aspect using an indilible marker to distinguish the coronal from the apical segments.

The radii of posts for each segment were measured coronally and apically using stereomicroscope (Nikon MA100 Japan) to be used further in calculating the area of the bonded post to tooth.

For the specimen to be fixed in place with no minute movements during the testing procedure, a custom made specimen holder was made to maintain the specimen in place while delivering the load.

The other compartment used for delivering the load was also custom-made metallic cylinder with a smaller stainless steel plunger of 4mm length and 0.9 mm diameter fixed on top of it. This small diameter ensured that the rod contacted only the post while exerting the load.

The two compartments were attached to the universal testing machine and the test was conducted at a cross head speed of 0.5 mm/min using a 500N load cell. Load was confined to the post area till debonding occurred and the post was seen extruded from the canal. The highest value recorded was taken as the push-out bond strength. Fig. (2)

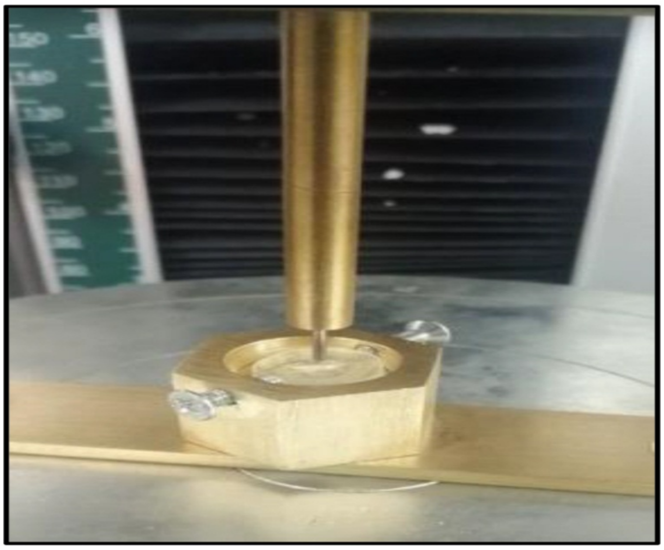

Fig. (2): Showing the post mounted on a straight handpiece while subjected to CO_2 laser beam.

The following equation was used to obtain the bond strength (σ) in MPa:

$$\sigma = F/A$$

While:

F: Debonding force in Newtons (N).

A: Bonded area to the tooth structure (mm2).

To calculate the bonded area (A) the following formula was used:

$$A = \pi \times g \times (R1+R2)$$

π: 3.14

g: Trunk generatrix

R1: smaller base radius

R2: larger base radius

h: Specimen height

Pythagorean Theorem will be used for (g) calculation

$$g2 = h2 + (R2-R1) \quad (14)$$

Statistical analysis

Data were collected and entered to the computer using SPSS (Statistical Package for Social Science) program for statistical analysis (ver 21) (15). Kolmogorov-Smirnov test of normality revealed no significance in the distribution of the variables, so the parametric statistics was adopted (16). Data were described using minimum, maximum, mean, standard deviation and 95% CI of the mean (17).

Comparisons were carried out between more than two independent normally distributed subgroups using one-way ANalysis Of VAriance (ANOVA) test (18). The F ratio of ANOVA was significant so Brown-Forsythe Robust test was adopted. Post-hoc multiple comparisons (19) was done using Games-Howell (20).

An alpha level was set to 5% with a significance level of 95%.

RESULTS

The mean value of debonding load was recorded in megapascals. The statistical analysis revealed that Group I had a mean of debonding load of (12.20±0.90 MPa) and (10.20±0.74 MPa) for group II while the mean of debonding load for Group III was (6.22±1.17 MPa). Table (1) and Fig. (3)

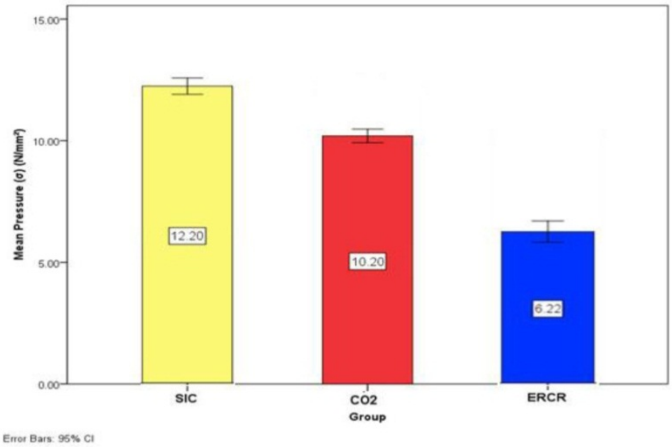

Fig. (3): Showing post mounted on a straight handpiece subjected to Er.Cr.YSGG laser beam.

Table (1): Statistical Analysis of the results

Pressure (σ) (N/mm²)	Group: Group (I) SIC	Group (II) CO2	Group (III) Er.Cr	Test of significance
- n	30	30	30	F(BF)=305.583 p=0.000*
- Min-Max	10.50-14.67	8.56-11.44	4.53-8.43	
- Mean ± Std. Deviation	12.20±0.901	10.20±0.74	6.22±1.17	
- 95% CI for mean	1.86–12.53	9.91–10.47	5.78 –6.65	
	Multiple Comparisons (Games-Howell method)			
	SIC	CO2	ErCr	
SIC		Diff= 2.005 p=0.000*	Diff= -3.977 p=0.000*	

Pressure (σ) (N/mm²)	Group			Test of significance
	Group (I) SIC	Group (II) CO2	Group (III) Er.Cr	
CO2			Diff= -3.982 p=0.000*	
ErCr				

One way ANOVA test was conducted and showed a statistically significant difference in the debonding load (Mpa) among the three studied groups ($p < 0.05$). Games-Howell post-hoc test was carried out between different groups and revealed that Group (I) showed the highest debonding load when compared to Group (II) ($p < 0.05$) and group (III) ($p < 0.05$). Group (II) showed higher debonding load when compared to Group (III) ($p < 0.05$) but lower to that of Group (I).

The one way ANOVA test showed no significant difference when comparing the debonding load at all coronal sections of the three groups to the load at all the middle and apical sections of the three groups. The coronal sections showed the highest values regardless the surface treatment used. Table (2) and Fig. (4)

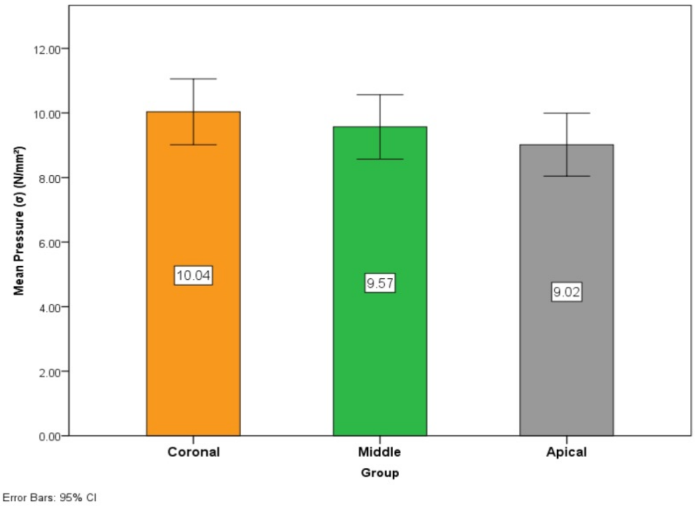

Fig. (4): Showing 2 compartments attached to the universal testing machine.

Table (2): Statistical Analysis of the results for all sections among three groups

Pressure (σ) (N/mm²)	Section			Test of significance
	Coronal	Middle	Apical	
- n	30	30	30	F(BF)= 1.096 p=0.339 NS
- Min-Max	5.21-14.67	4.70-13.86	4.53-13.12	
- Mean ± Std. Deviation	10.04±2.73	9.57±2.67	9.02±2.61	
- 95% CI for mean	9.01 –11.05	8.57–10.56	8.04–9.99	
	Multiple Comparisons (Games-Howell method)			
	Coronal	Middle	Apical	

Pressure (σ) (N/mm²)	Section			Test of significance
	Coronal	Middle	Apical	
Coronal		Diff= 0.466 p=0.782 NS	Diff= 1.019 p=0.309 NS	
Middle			Diff= 0.553 p=0.697 NS	
Apical				

Stereomicroscopic study revealed that specimens treated with tribochemical silica coating had a considerable amount of resin cement remaining on the surfaces of the debonded post portions showing a 100% adhesive/cohesive failure. However specimens treated with CO2 laser also showed some mixed types of failure along with completely adhesive failure in other specimens. It was also found that specimens subjected to Er.Cr.YSGG showed a majority of adhesive failure at the post-cement interface and no mixed failure types were observed.

DISCUSSION

In the current study the effect of different surface treatments was evaluated for inducing some surface changes that will affect the bond strength between tooth structure and Y-TZP surface of zirconia posts being milled according to a previous scan for a glass fiber post of the same size to standardize the length and diameter of all posts. It was the aim of this study to evaluate the effect of different surface treatments to the zirconia posts without any aging effects induced to avoid any stresses being generated as a result of the different thermal coefficient of the materials used or bond degradation at the interfaces by hydrolysis (21). On the basis of the present data, the null hypothesis was rejected.

All specimens were subjected to a push-out test to evaluate the maximum load needed before debonding occurred. The push-out test was selected to be adopted in this study as it offered an acceptable compromise for the drawbacks of tensile and shear stresses where non-uniform forces are exerted on the tooth surface as a result of the large surface area bonded to the posts (22). Microtensile test overcame this drawback of the previous tests giving better uniform stress distribution due to smaller-sized specimens having smaller surface areas bonded. Unfortunately, a high rate of premature failure was encountered in addition to large data distribution was also needed. So push-out tests were found to have smaller bonded surface areas along with absence of premature failures and parallelity of the applied force to the interface (23).

Tribochemical silica coating showed to have the highest push-out bond strength results when compared to those of CO2 and Er.Cr.YSSG laser groups so the null hypothesis was rejected.

These results were similar to those obtained by Akyil et al (24) who stated that TSC was found to improve the bond strength and Gomes et al., (21) who found that TSC showed more durable bond strength values even when subjected to thermocycling. In this study, silica coated Al2O3 particles was chosen over air abrasion by conventional AL2O3 particles as it provides a chemical affinity for zirconia to silane in addition to the mechanical interlocking provided by air abrasion.

Several studies (21, 25-27) reported that the silica coating for Y-TZP surface achieved better bond strength than air abrasion for resin bonding. However, it was found that using tribochemical coating could result in a non-uniform silica layer being embedded into the surface, which subsequently could show some variation in bond strength. Moreover, zirconia is a material with a higher surface hardness, smaller crystal size and higher density than glass ceramics; these physical properties make it hard for the silica particles to be bonded to the surface (28).

Even when trying to increase the silica layer thickness by vapor-deposition, these additional layers are partially bonded together by van der walls which are secondary chemical bonds that showed no significance in increasing the chemical bonding to the luting cement over the traditional silica coating procedure (29).

In this study, it was found that using CO2 laser was beneficial in achieving some surface changes and thus enhancing the bond strength to luting cements. These surface changes were represented in the form of trench-like depressions and micro-porosities giving some means of micro-roughness to the surface for further adhesion .The results for this study confirmed those obtained by Akyil et al., (24) when CO2 laser was used solely on to the ceramic surface. However, it was found in the same study that using CO2 laser along with air abrasion showed a decrease in the bond strength. Stubinger et al., (30) found distinct ceramic surface changes with using (4.5 W) output power which showed durable bond strength. In the current study, results were found to be similar to those of Kunt et al., (31) and Kasraei et al., (12) who used (4 W) and (3W) CO2 laser respectively and observed some significant surface alterations. The laser parameters were chosen according to the previous studies (11,12) to have a ceramic surface with some surface alterations that can help as mechanical retention along with the (MDP) containing resin cement and at the same time to have a surface free of flaws or extensive cracking.

The most crucial effect of laser energy is transforming of light energy into heat, absorbing the laser energy by the ceramic surface is the main interaction that takes place (32,33). According to Akyil (24), who observed the effect of CO2 and Nd.YAG lasers as surface treatments for Y-TZP, stated that porosities are formed as a result of a process of heat induction on the surface of the ceramic. These porosities allow resin to penetrate and harden inside providing micromechanical bond with the ceramic. On the contrary Akin et al., (35) found that by using CO2 with an energy density of (159,22J/cm2), smooth surface for the ceramic resulted with very limited amount of scaly fissures and surface roughness thus resulting in less weaker bond strength value compared to that of air abrasion. Kasarei et al., (12) studied the effect of CO2 lasers on zirconia and attributed this failure to the low energy density used which was below the material threshold for absorption and thus failing to induce any surface modification to the ceramic surface.

Other factors that govern the absorption of laser energy by zirconia as explained by Kunt et al., (31) are the pigments incorporated in the ceramic and water content. Since zirconia is a white opaque material and devoid of water content, this makes it a material of low affinity for absorption of laser energy.

Er,Cr:YSGG laser system has no enough data shown concerning its effect on improving the bond strength to zirconia ceramics. This system has the capability of modifying the surfaces by ablation process which is regarded as removing the surface particles via a process of vaporization and some microexplosions (35, 36).

The findings of the current study were found to be congruent to those of Ghasemi et al. who showed that using Er,Cr:YSGG in a (2W) output power didn't have a significant effect in improving the bond strength whether used in a pre-sintered or a sintered state (37). Er.Cr:YSGG failed to show significant surface alterations when compared to those found in silica coating and CO2 groups and the surface was found to have nearly a similar topography to that of an untreated surface.

Similarly, Miranda et al. compared the effect of Er.Cr:YSGG on the surface alterations created in (Y-TZP) and titanium discs and found that using Er,Cr:YSGG showed to have a decreased surface roughness than the untreated specimens (38). In the present study failure of the Er,Cr:YSGG to cause significant surface changes may be attributed to long exposure time of post surface to the laser which in turn caused an increase in the temperature and damaged the ceramic surface by creating deep surface cracking rather than creating any topographic changes.

On the other hand, a study conducted by Yilmaz and Aktore showed some topographic changes which took place when Er.Cr.YSGG laser was used in a (3W) output power and were found to be similar to those found when CO2 laser in a (4W) output power was used (13). Yet at the same time, using higher output power ranging from (5-6 W) was found to form detrimental effects to the ceramic surface owing to the increased surface temperature along with a subsequent tetragonal to monoclinic transformation (39). Accordingly the laser parameters in this study were determined.

On using a stereomicroscope to inspect the mode of failure, it was observed that in most of the laser-group samples, the mode of failure was mainly adhesive meaning that debonding occurred at the interface between the resin cement and the post. The findings were similar to those obtained by other studies (12, 36, 40). On the other hand, most of the specimens in the (TSC) group showed a mixed type of failure which means that ruptures took place at the interface (adhesive) in addition to the cohesive failure within the resin cement. The findings of the current study were consistent with a previous study stating that air abrasion group showing a mixed type and an adhesive failure in CO2 and Er.Cr:YSGG groups (12). Using a chairside air abrasion device with 30-µm Al2O3 as a method of TSC or using CO2 laser device are clinically feasible and could enhance the bond strength while bonding to zirconia posts rather than placing posts with no surface treatments or using Er.Cr.YSGG laser since an adhesive failure is most probably the type of failure that would be encountered.

In this study, the tribochemical silica coating was considered as a positive control to be compared with the other two groups as it was considered the surface treatment of choice for bonding to zirconia by many studies. However, the current study lacks information about the results of the three groups and a group of untreated zirconia surfaces which is considered a limitation of this study along with lacking of aging procedures

CONCLUSION

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

1. Tribochemical silica coating is an effective way that is regarded a micromechanical mean of retention along with chemical bonding of zirconia ceramic to the luting cement.
2. CO2 lasers proved to be a better laser system to be used as a method of surface treatment than Er.Cr:YSGG but both systems were found to be inferior to (TSC).

Conflict of Interest

The authors declare that they have no conflict of interest.

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REFERENCES

1. Ozkurt Z, Işeri U, Kazazoğlu E. Zirconia ceramic post systems: a literature review and a case report. Dent Mater J. 2010;29:233-45.
2. Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont. 2001;14:355-63.
3. Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent. 2002;87:431-7.
4. Galhano GA, Valandro LF, De Melo RM, Scotti R, Bottino MA. Evaluation of the flexural strength of carbon fiber-, quartz fiber-, and glass fiber-based posts. J Endod. 2005;31:209-11.
5. Balbosh A, Kern M. Effect of surface treatment on retention of glass-fiber endodontic posts. J Prosthet Dent. 2006;95:218-23.
6. Meyenberg KH, Luthy H, Schaerer P. Zirconia posts: a new all-ceramic concept for nonvital abutment teeth. J Esthet Dent. 1995;7:73-80.
7. Bateman G, Ricketts DN, Saunders WP. Fibre-based post systems: A review. Br Dent J. 2003;195:43-8.
8. Kulunk S, Kulunk T, Ural C, Kurt M, Baba S. Effect of air abrasion particles on the bond strength of adhesive resin cement to zirconia core. Acta Odontol Scand. 2011;69:88-94.
9. Dietschi D, Romelli M, Goretti A. Adaptation of adhesive posts and cores to dentin after fatigue testing. Int J Prosthodont. 1997;10:498-507.
10. Akgungor G, Sen D, Aydin M. Influence of different surface treatments on the short-term bond strength and durability between a zirconia post and a composite resin core material. J Prosthet Dent. 2008;99:388-99.
11. Kasraei S, Atefat M, Beheshti M, Safavi N, Mojtahedi M, Rezaei-Soufi L. Effect of Surface Treatment with Carbon Dioxide (CO2) Laser on Bond Strength between Cement Resin and Zirconia. J Lasers Med Sci. 2014;5:115-20.
12. Ural C, KalyoncuoĞlu E, Balkaya V. The effect of different power outputs of carbon dioxide laser on bonding between zirconia ceramic surface and resin cement. Acta Odontol Scand. 2012;70:541-6.
13. Akhavan Zanjani V, Ahmadi H, Nateghifard A, Ghasemi A, Torabzadeh H, Abdoh Tabrizi M, et al. Effect of different laser surface treatment on microshear bond strength between zirconia ceramic and resin cement. J Investig Clin Dent. 2015;6:294-300.
14. Baldea B, Furtos G, Antal M, Nagy K, Popescu D, Nica L. Push-out bond strength and SEM analysis of two self-adhesive resin cements: An in vitro study. J Dent Sci. 2013;8:296-305.
15. IBM Corp. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.; 2012.
16. Field A. Discovering Statistics Using IBM SPSS Statistics. 4th ed. London, California, New Delhi: SAGE Publications Ltd; 2013.
17. Snecdecor GW, Cochran WG. Statistical Methods. Hoboken, New Jersey: Wiley; 1991. pp. 14-29.
18. Douglas CM. Experiments with a Single Factor: The Analysis of Variance. In: Design and analysis of experiments. 9th ed. Ch 3. Hoboken, NJ: John Wiley & Sons, Inc; 2017. pp.64-125.
19. Lowry R. One Way ANOVA–Independent Samples. Vassar. edu. 2008.
20. Ruxton GD, Beauchamp G. Time for some a priori thinking about post hoc testing. Behav Ecol. 2008;19:690-3.
21. Gomes AL, Ramos JC, Santos-del Riego S, Montero J, Albaladejo A. Thermocycling effect on microshear bond strength to zirconia ceramic using Er:YAG and tribochemical silica coating as surface conditioning. Lasers Med Sci. 2015;30:787-95.
22. Goracci C, Grandini S, Bossù M, Bertelli E, Ferrari M. Laboratory assessment of the retentive potential of adhesive posts: a review. J Dent. 2007 ;35:827-35.
23. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, et al. The adhesion between fiber posts and root canal walls: comparison between microtensile and push-out bond strength measurements. Eur J Oral Sci. 2004;112:353-61.
24. Akyil MS, Uzun IH, Bayindir F. Bond strength of resin cement to yttrium-stabilized tetragonal zirconia ceramic treated with air abrasion, silica coating, and laser irradiation. Photomed Laser Surg. 2010;28:801-8.
25. Ozcan M, Vallittu PK. Effect of surface conditioning methods on the bond strength of luting cement to ceramics. Dent Mater. 2003;19:725-31.
26. Amaral R, Ozcan M, Valandro LF, Balducci I, Bottino MA. Effect of conditioning methods on the microtensile bond strength of phosphate monomer-based cement on zirconia ceramic in dry and aged conditions. J Biomed Mater Res B Appl Biomater. 2008;85:1-9.
27. Valandro LF, Della Bona A, Antonio Bottino M, Neisser MP. The effect of ceramic surface treatment on bonding to densely sintered alumina ceramic. J Prosthet Dent. 2005;93:253-9.
28. Kern M, Wegner SM. Bonding to zirconia ceramic: adhesion methods and their durability. Dent Mater. 1998;14:64-71.
29. Smith RL, Villanueva C, Rothrock JK, Garcia-Godoy CE, Stoner BR, Piascik JR, et al. Long-term microtensile bond strength of surface modified zirconia. Dent Mater. 2011;27:779-85.
30. Stübinger S, Homann F, Etter C, Miskiewicz M, Wieland M, Sader R. Effect of Er:YAG, CO(2) and diode laser irradiation on surface properties of zirconia endosseous dental implants. Lasers Surg Med. 2008;40:223-8.
31. Ergun Kunt G, Duran I. Effects of laser treatments on surface roughness of zirconium oxide ceramics. BMC Oral Health. 2018;18:222.
32. Coluzzi DJ. Fundamentals of dental lasers: science and instruments. Dent Clin North Am. 2004;48:751-70.

33. Cavalcanti AN, Pilecki P, Foxton RM, Watson TF, Oliveira MT, Gianinni M. et al. Evaluation of the surface roughness and morphologic features of Y-TZP ceramics after different surface treatments. Photomed Laser Surg. 2009;27:473-9.
34. Akin H, Tugut F, Akin GE, Guney U, Mutaf B. Effect of Er:YAG laser application on the shear bond strength and microleakage between resin cements and Y-TZP ceramics. Lasers Med Sci. 2012;27:333-8.
35. Cho SD, Rajitrangson P, Matis BA, Platt JA. Effect of Er,Cr:YSGG laser, air abrasion, and silane application on repaired shear bond strength of composites. Oper Dent. 2013;38:E1-9.
36. Cavalcanti AN, Foxton RM, Watson TF, Oliveira MT, Giannini M, Marchi GM. Bond strength of resin cements to a zirconia ceramic with different surface treatments. Oper Dent. 2009;34:280-7.
37. Ghasemi A, Kermanshah H, Ghavam M, Nateghifard A, Torabzadeh H, Nateghifard A, et al.. Effect of Er,Cr:YSGG laser treatment on microshear bond strength of zirconia to resin cement before and after sintering J Adhes Dent. 2014;16:377-82.
38. Miranda PV, Rodrigues JA, Blay A, Shibli JA, Cassoni A. Surface alterations of zirconia and titanium substrates after Er,Cr:YSGG irradiation. Lasers Med Sci. 2015;30:43-8.
39. Kurtulmus-Yilmaz S, Aktore H. Effect of the application of surface treatments before and after sintering on the flexural strength, phase transformation and surface topography of zirconia. J Dent. 2018;72:29-38.
40. Spohr AM, Borges GA, Junior LH, Mota EG, Oshima HM. Surface modification of In-Ceram Zirconia ceramic by Nd:YAG laser, Rocatec system, or aluminum oxide sandblasting and its bond strength to a resin cement. Photomed Laser Surg. 2008;26:203-8.