ORIGINAL RESEARCH

A Shift to Synergistic Surface Treatment Using Laser to Enhance the Bonding of Zirconia to Veneering Ceramic: An *In Vitro* Study

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Abstract

Aim: The aim of this study was to evaluate the effect of combination of surface treatment using laser along with other modalities of surface treatment on shear bond strength of zirconia to veneering ceramic.

Materials and methods: Milled and sintered zirconia cylinders ($n = 150$) were used in the study which were divided into six groups that were subjected to various surface treatments. Samples in group I were subjected to sandblasting. In group II Laser (Er: YAG) surface treatment was performed. Samples in group III were subjected to sandblasting followed by laser ablation. In group IV laser ablation was carried out followed by liner application, and samples in group V were subjected to laser ablation followed by argon plasma treatment. Instron machine was used to test the shear bond strength (SBS). One-way ANOVA and Bonferroni test were used for statistical analysis.

Result: Samples in group III showed highest values for SBS followed by groups I, IV, and V with less SBS value for group II.

Conclusion: Thus, the results conclude the use of combination of surface treatment using laser to be an effective modality to enhance the shear bond strength of zirconia.

Clinical significance: Synergistic surface treatment using laser increases the bond strength of zirconia prosthesis to veneering ceramic improving its clinical longevity.

Keywords: Air abrasion, Bond strength, Er YAG laser, Yttria-stabilized tetragonal zirconia polycrystal.

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Introduction

In recent times, prosthetic rehabilitation has its focus on esthetics necessitating the use of all ceramic materials as restorative material. Excellent translucency of all ceramic material has made it to be more advantageous in crown and fixed dental prosthesis-making. However, its inferior mechanical property limits its use to low stress-bearing area. Zirconia ceramic, an evolutionary high strength ceramic, has overcome the shortcoming of traditional glass ceramic with its superior mechanical properties.[1]

Zirconium dioxide (ZrO_2) exists in three crystal forms, namely, tetragonal phase at room temperature, monoclinic phase at firing temperature, and cubic phase at fusion temperature. Firing causes a transition from tetragonal to monoclinic form and while cooling down there is 3–5% increase in volume. This volume increase aids in toughness but makes the material more prone to fracture. In order to prevent this phase transition, Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) were developed which is regarded as an optimal dental material with supreme properties of biocompatibility, high flexural strength, and fracture toughness which allows its use in high stress-bearing areas.[2,3] Low translucency being its major disadvantage, zirconia coping would require application of veneering ceramic to enhance esthetics.[1–3]

A clinical study reports the clinical failure rate of veneered Y-TZP framework to be 13% after 3 years and 15.2% after 5 years whereas that for metal ceramic FPDs were 8–10% after 10 years.[4,5] A major mode of failure was ceramic chipping due to delamination.[4] Adequate bond strength between zirconia substructure and veneering ceramic is therefore a major concern for extended clinical durability of restoration.[6] Factors affecting the bond strength of bilayered restoration are diverse which includes mechanical interlocking, strength of chemical bond, type and concentration of defect at interface and wetting property.[7]

So far, diverse surface treatments have been adopted to improve bonding acting either chemically or by causing mechanical interlocks. Most commonly used conventional surface treatments are sandblasting, mechanical grinding, liner application, silica coating, and hot acid etching. Contemporary treatment modalities are plasma treatment and laser treatment.[8]

Sandblasting is a well-known surface treatment that removes loose contaminated layers and increases the area available for bonding. This process causes phase transition of superficial

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layer from tetragonal to monoclinic form which results in crack propagation due to lower coefficient of thermal expansion of monoclinic phase. This negatively affects the bond strength.[6]

Currently, lasers including CO_2, Er:YAG, Er:Cr:YSGG, diode, and Nd:YAG are gaining increased popularity as they are utilized in various dental procedures like bleaching, caries removal, dentin desensitization, dentin conditioning, and roughening ceramic surface.[9]

Er:YAG laser, a hard tissue laser, has proved to be effective in the bonding of resin cement to zirconia altering its surface. The mechanism behind the Er:YAG laser irradiation of zirconia is the temperature change of lased zirconia that causes irregularities by repeated melting and rehardening.[10]

Recent study by Kirmali et al. showed enhanced bond strength using the combination of the above-mentioned surface treatments on presintered zirconia samples.[8] Limited knowledge is available on the combined use of different surface treatments with Er:YAG laser irradiation on postsintered zirconia which would serve as a more effective method of enhancing shear bond strength with enhanced flexural strength. Thus, the objective of this study was to evaluate and compare the effect of Er:YAG laser treatment and combination of surface treatment on the shear bond strength of zirconia to veneering ceramic. The null hypothesis formulated was that there would be no difference in shear bond strength after various surface treatments.

Materials and Methods

Study Design

The present *in vitro* study was conducted in the Department of Conservative Dentistry and Endodontics, Government Dental College and Research Institute, Bengaluru, India.

Sample Size

The sample included 150 presintered zirconia cylinders fabricated from zirconium oxide blocks (Amann Girrbach, Germany).

Sample Preparation

A stainless-steel mould with the dimensions of 10 mm diameter and 18 mm height was fabricated and set up in a holder. The mould was scanned with CAD-CAM scanner (Amann Girrbach, Germany). Cylindrical specimens of the uniform size from zirconia blocks (Amann Girrbach, Germany) were made from the scanned model. Milling of presintered zirconia blocks was carried out as per the instructions of manufacturer.

The milled zirconia cylinders were subjected to cleaning and drying. Sintering was then carried out. Standardized surface roughness was achieved by polishing the bonding surface of samples with diamond paste using a rotating metallographic polishing device under a fixed load and water cooling. Silicon carbide paper was used in an ascending stepwise manner with 120 grit through 120-, 240-, 320-, 400-, 600- to finishing in 800 grit silicon carbide paper. One-hundred and fifty samples were randomly divided into five pre-treatment groups (30 in each group):

Surface Treatment Methods

Group I: Sandblasting 50/30 Microns and 3.5 Bar Pressure

Sandblasting was done with alumina particles of 50/30 µm particle size at a distance of 1 mm from the surface at 3.5 bar pressure for a duration of 15 seconds.

Group II: Laser

Er:YAG with a wavelength of 2.94 µm holds its use as hard tissue laser. The laser system (light touch in the Department of Conservative Dentistry and Endodontics, GDCRI, Bengaluru) was used according to manufacturer's instructions. Cylindrical sapphire tip with diameter of 1.3 mm and length of 8 mm was used for laser irradiation. The tip was directed perpendicular to the surface in a noncontact mode at a distance of 1 mm. The parameters include 300 mJ/pulse energy for 20 seconds, and 10 Hz frequency.

The Er:YAG pulsed laser of wavelength 2.94 µm used power settings of 300 mJ pulse energy frequency of 10 Hz with a focal distance of 1 mm for 20 seconds. Intermittent air cooling and water spray were used throughout the procedure (Fig. 1A).

Group III: Sandblasting 50/30 Microns and 3.5 Bar Pressure + Laser

Alumnium oxide (Al_2O_3) airborne-particle abrasion was performed in a similar way as mentioned under group I. The sandblasted specimens were then subjected to Er:YAG laser ablation.

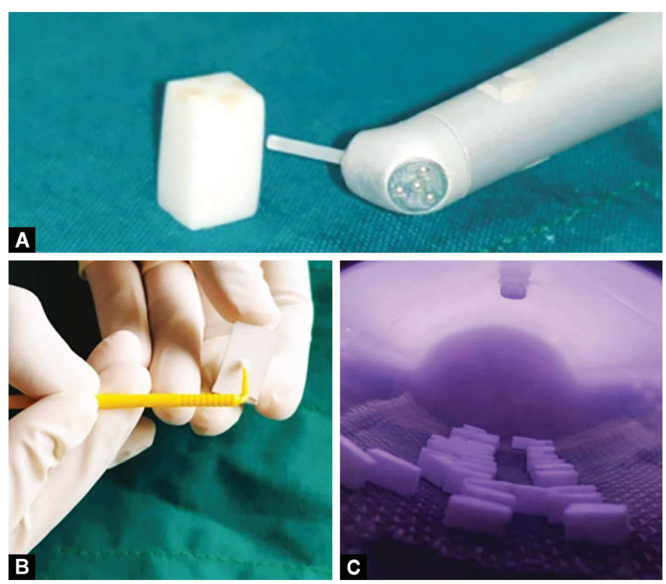
Group IV: Laser + Liner

Laser ablation was carried out as described under group II. This was followed by the application of liner (Emax Ceram Zirliner) as advised by the manufacturer (Fig. 1B).

Group V: Laser + Argon Plasma

Laser ablation of prepared specimens as described under group II. Argon plasma treatment was then carried out with plasma jet using argon gas for a duration of 30 seconds. Plasma treatment parameters used in the study were 220 V electric voltage, power of 100 W with constant gas pressure of 1 kg/cm^2, and gas flow 8.5 L/minute (Fig. 1C).

Finally, 96% isopropyl alcohol was used to clean the prepared specimens ultrasonically for 3 minutes followed by steam-cleaning for 15 seconds.



Figs 1A to C: Surface pretreatment of zirconia specimens. (A) Laser irradiation; (B) Liner application; (C) Argon plasma treatment

Shear Bond Strength Test (SBS)

Application of Porcelain

Manual layering technique was used for porcelain veneering. Initially, two layers of liner porcelain were brushed and firing was done. Vibration blotting technique was then used for condensation of dentin porcelain. Firing was performed as per manufacturer and then a final glaze was obtained.

The samples were stored in distilled water at 37°C for 1 week and thermocycling was done for 5,000 cycles at 5–55°C with a 30-seconds dwell time.

The assembly was then mounted in universal testing machine. Samples were subjected to shearing load at 0.5 mm/minute crosshead speed. The final load to which fracture occurred was measured in Newton (N). The SBS value in MPa was estimated as follows:

$$\text{Shear stress (MPa)} = \text{Load (N)/surface area (mm}^2\text{)}$$

Scanning electron microscopic (SEM) evaluation was done to assess the surface characteristics. Image of each surface was registered at 1,000× magnification.

Statistical Analysis

Data were subjected to normalcy test (Shapiro-Wilk test). Data showed normal distribution. The shear bond strength values between the zirconia core and the veneer ceramic were evaluated with one-way analysis of variance (ANOVA). *Post-hoc* Bonferroni test was applied for intergroup comparison. Results were displayed in the form of mean values with standard deviations for each parameter combination and were considered statistically significant when $p < 0.05$. A SPSS 26.0 software (Chicago Inc., USA) was used for statistical analysis.

Results

Significant difference between the groups in regard to the mean bond strength was observed when one-way ANOVA was used ($p = 0.00$) (Table 1). *Post-hoc* Bonferroni test revealed statistically significant difference between the groups except between Laser and Sandblasting ($p = 1.00$), Laser + Liner and Sandblasting ($p = 0.09$); Laser + Liner and Sandblasting + Laser ($p = 0.33$) (Table 2).

Samples treated with Sandblasting + Laser (49.19) showed highest mean shear bond strength followed by the group Sandblasting (32.9), Laser + Liner (28.98), Laser + Argon Plasma (24.15), and the least for Laser Group (21.35) (Fig. 2).

Thus, the present study infers that the group subjected to synergistic surface treatment of sandblasting followed by laser ablation increased the shear bond strength significantly followed by the group treated with sandblasting.

SEM Result

SEM images revealed range of irregularities on the surface of zirconia specimens. Highest surface roughness with microretentive areas was observed in group in which samples were treated with sandblasting followed by laser treatment. Sandblasting group showed some degree of surface roughness whereas smooth surface with microcracks was observed in group in which only laser ablation was carried out (Figs 3A to C). Liner and argon plasma group showed irregular layer formed along with few pits over surface (Figs 3D and 4).

Discussion

Clinical studies report the major mode of failure of zirconia prosthesis to be the chipping or delamination of veneering ceramic

Table 1: Comparison of the mean shear bond strength among the groups using ANOVA

Groups	*N*	*Minimum*	*Maximum*	*Mean*	*SD*	*F value*	*p value*
Laser	30	14.30	28.30	21.35	3.29		
Laser + argon plasma	30	13.80	37.50	24.15	6.13		
Laser + liner	30	17.80	45.40	28.98	7.13	71.917	0.00*
Sandblasting	30	15.40	48.50	32.90	8.92		
Sandblasting + laser	30	33.90	62.30	49.19	8.40		

*Significant

Table 2: Intergroup comparison of shear bond strength using *post-hoc* Bonferroni

				95% confidence interval	
Group	*Groups*	*Mean difference*	*p value*	*Lower bond*	*Upper bond*
Laser	Laser + argon plasma	−27.84	0.00*	−33.04	−22.64
	Laser + liner	−7.64	0.00*	−12.83	−2.44
	Sandblasting	−2.80	1.00	−8.00	2.39
	Sandblasting + laser	−11.56	0.00*	−16.75	−6.36
Laser + argon plasma	Laser + liner	20.21	0.00*	15.01	25.40
	Sandblasting	25.04	0.00*	19.84	30.24
	Sandblasting + laser	16.29	0.00*	11.09	21.48
Laser + liner	Sandblasting	4.83	0.09	−0.37	10.03
	Sandblasting + laser	−3.92	0.33	−9.12	1.28
Sandblasting	Sandblasting + laser	−8.75	0.00*	−13.95	−3.55

*Significant

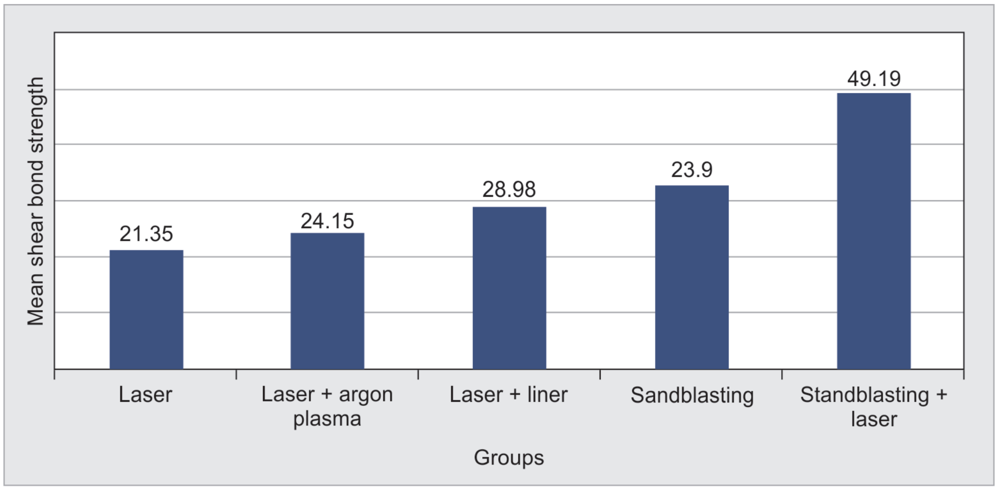
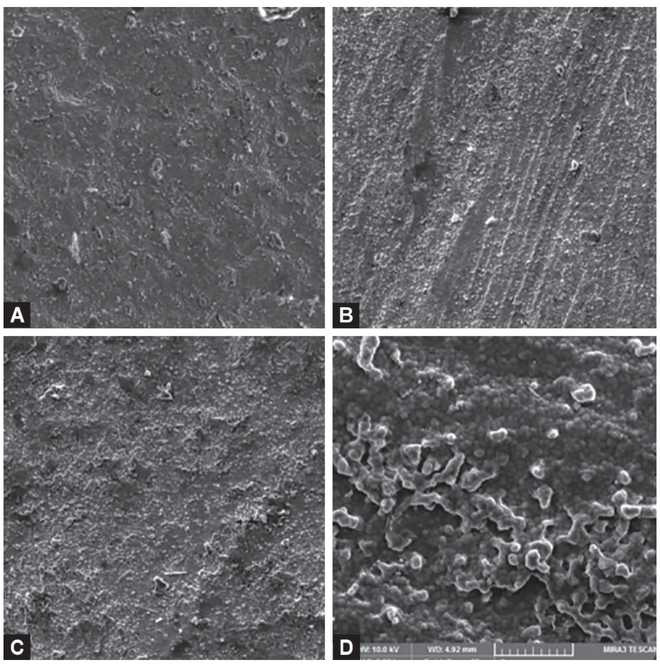


Fig. 2: Shear bond strength in megapascals



Figs 3A to D: SEM images after various surface treatments. (A) Sandblasting; (B) Laser irradiation; (C) Sandblasting + laser; (D) Laser + liner

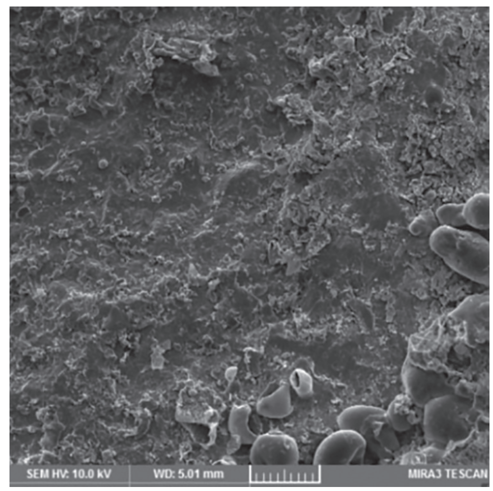


Fig. 4: SEM image of Laser + argon plasma surface treatment

from the zirconia core. Thus, off late, focus has been to enhance the bonding of zirconia core and ceramic veneer interface. Considerable research work has been done using different surface treatments such as sandblasting, liner application, silica coating, and hot acid etching. In an attempt to discover more efficient surface treatment, contemporary methods such as laser irradiation and argon plasma treatment were adopted and have shown promising results.[1–6]

Thus, the present study adopted the novel strategy of combining surface treatments with laser irradiation to evaluate its effect on the adhesion of zirconia to ceramic veneer on presintered zirconia specimens with sandblasting as a positive control group. The null hypothesis is rejected as the result shows statistically significant difference between groups with highest bond strength values for the group treated with sandblasting + laser irradiation followed by sandblasting group.

Increasing the surface roughness is the most common strategy in improving bond strength. On this account, sandblasting stands to be the most efficient surface treatment. The possible mechanism stated is that it removes the loose contaminated layers and increases the area available for bonding. Thus, sandblasting has been used as a positive control for the study.[11–13]

In recent years, laser has been popularly used in various dental procedures. Laser etching has been adopted as a surface treatment for zirconia. Hakan akin et al. suggests that the use of laser irradiation significantly improved the shear bond strength of zirconia to resin cement when compared to untreated control group.[12]

Coluzzi et al. through his study states that laser surface treatment might be an optimal solution to improve bond strength as the action of laser on ceramic is superficial without affecting properties of the material. The reason for this was the minimal penetration depth of laser on zirconia.[13] Thus, in the present study, laser was used as a major surface treatment to be used in combination with other surface treatments (sandblasting, liner, argon plasma).

Interaction between laser and matter is the thermomechanical effect where the energy is absorbed on to the surface. Laser parameters directly influence the amount of energy and thermal action on the surface. This increased temperature causes the zirconia material to deteriorate making this less efficient as a surface treatment. In Er:YAG laser, pulse duration has influence on the peak power which ultimately affects the properties of the material surface. Parameters set for laser irradiation essentially influence the bond strength.[14]

Hou et al. studied the influence of laser parameters on ceramics by comparing groups with different laser power settings of 100, 200, 300, 400, 500, and 600 mJ. His findings suggest the use of laser at 300 and 400 mJ to have the strongest bond in comparison to other groups.[15] Thus, the present study utilized Er:YAG laser with 300 mJ/pulse energy, duration of 20 seconds, focal distance of 1 mm, and 10 Hz frequency.

The mechanism of action of Er:YAG laser irradiation on tooth structure is based on chromophore theory, where laser absorption occurs through colored molecule leading to microexplosion and vaporization causing surface roughness. However, this process is not applicable to zirconia pretreatment due to the absence of both water and pigment molecule for the laser interaction with the surface of the material. Thus, possible process occurring could be the conversion of laser energy into heat energy and pressure causing irregular surface morphology which enhances the adhesion between zirconia and ceramic veneer.[16]

The present study shows comparatively lower bond strength for laser irradiation alone which is in agreement with study done by Akyil et al. in which specimens were subjected to various surface treatments with air abrasion, silica coating, Er:YAG, Nd:YAG, and CO_2 laser. The results showed significantly increased shear bond strength of zirconia to resin cement after air abrasion when compared to the specimens that were irradiated with Er:YAG laser.[17]

The highest bond strength value was obtained when laser irradiation was done after air abrasion. Similar results were obtained in study done by Kirmali et al. in which presintered zirconia specimens were subjected to various surface treatments which showed highest bond strength for sandblasting + Er:YAG laser followed by sandblasting.[9] However, the present study used postsintered zirconia specimens as Kurtulmus-Yilmaz et al. in his study reported an increased flexural strength when surface treatment was done on postsintered zirconia than on presintered blocks.[18] This may be attributed to the initial roughness caused by sandblasting which is optimized by laser irradiation causing formation of more retentive areas. Laser irradiation causes microexplosion which may cause the flecks to cling over melted ceramic surface improving its surface characteristic favorable for bonding.[19]

Akyil et al. compared groups treated with different lasers (Er:YAG, Nd:YAG, and CO_2) along with sandblasting. The results showed inferior bonding ability in group with sandblasting + Er:YAG laser which was in contrary to the present study. Power setting of 200 mJ was used in this study.[16]

Controversial studies exist with the use of liner application as surface treatment. Kim et al. suggests that use of liner was no way helpful in increasing the bond strength when compared to sandblasting. This could be due to generation of film at the interface that might interfere with bonding. Similarly, the result of this study proves laser + liner to be less effective compared to sandblasting and sandblasting + laser group.

Cannulo et al. in his study used argon plasma as a surface treatment for enhancing bond strength of zirconia to resin cement and proved it to be an efficient surface treatment. It acts by removing surface impurities, increasing surface energy, and wettability of zirconia. Nonetheless, it does not surpass the effect produced by sandblasting which is considered to be gold standard.[20] Likewise, the present study also shows relatively lesser bond strength compared to Laser + sandblasting and sandblasting group.

The results of the present study are compliant with the conclusion of systematic review by Caroline et al., which states that the bond strength is improved when the novel synergistic surface treatment is adopted as there is optimization of different properties of the material.[21,22]

Fewer studies exist on the effectiveness of this novel synergistic surface treatment strategy in enhancing the adhesion of zirconia core to veneering ceramic interface. The present research did not include presintered specimens in order to compare its effectiveness with postsintered specimens which could be limitation of the study. Thus, more studies are required using different combinations of existing surface treatments. Further studies are required on clinical performance of zirconia prosthesis following this novel surface treatment approach in order to gain knowledge on its long-term performance in multifactorial oral environment.

Conclusion

The present study reveals a significant increase in bonding of zirconia core to ceramic veneer in group treated by sandblasting followed by Er:YAG laser irradiation. Novel synergistic approach of surface treatment using Er:YAG laser has proven to enhance the bond strength of zirconia to veneering ceramic.

Clinical Significance

Ceramic chipping and delamination pose deleterious effect on the extended clinical durability of zirconia prosthesis with veneering ceramic. This study adopts a combination of laser surface treatment to increase the bond strength.

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