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The Influence of Combined Surface Treatmentsusing Plasma of Argon, Er:Yag Laser and Sandblasting on the Shear Bond Strength of Zirconia Core to the Veneering Ceramic – In Vitro Study

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ABSTRACT

Background: Success of zirconia-based prosthesis is greatly affected by ceramic chipping and delamination due to poor bonding between zirconia framework and veneering ceramic. This study uses combination of surface treatment with Non-thermal Argon Plasma to evaluate its effect on Shear Bond Strength (SBS).

Objective: The study aimed to evaluate the effect of different surface treatment using sandblasting, argon plasma, Er:YAG laser and its combination on SBS of zirconia to veneering ceramic.

Material and Method: 150 milled and sintered zirconia blocks (10mm x 18mm) were subjected to various surface treatments and were randomly divided into five groups according to the surface treatment methods namely.

Group 1: Argon plasma(220 V,100W and constant gas pressure 1 kg/cm^2 and gas flow 8.5L/min) + Liner (E max ceram zirliner), **Group 2**: Atmospheric pressure argon plasma, **Group 3:** Sandblasting, **Group 4:** Sandblasting + Laser ablation (Er:YAG ; 300mJ/pulse energy, frequency-10Hz) + Argon plasma and **Group 5:** Sandblasting + Argon plasma. Specimens were subjected to shear bond strength test by a universal testing machine with a crosshead speed of 1 mm/min. The data were analysed with one-way ANOVA and Bonferoni test for multiple comparisons tests (α=0.05).

Result: Highest shear bond strength value was obtained for Group 4 followed by Group 5, Group 3, Group 2 with least value obtained for Group 1.

Conclusion: This study shows that sandblasting + Er:YAG + Argon plasma showed higher shear bond strength when compared to other groups.

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Need for the Study

Esthetics has been an emerging field in restorative dentistry. Zirconia is one such material that satisfies the aesthetic, functional and biological demands due to its inherit optical and mechanical properties. However its opaque appearance necessitates veneering its surface with a layer of ceramic to enhance aesthetics. Chipping or fracture of the veneered ceramic is not uncommon and results in failure of the prosthesis. Various surface treatment modalities have been described in the literature to enhance the bonding between zirconia core and the veneering material. Likewise the present study also utilises various surface treatment modalities using Argon plasma, Er:YAG laser, Sandblasting and its combination to determine the best possible method that would result in a long-lasting and durable bonding between the zirconia and veneered ceramic.

Introduction

Esthetics in dentistry has been has been an emerging field, and its success in the last few years can be greatly attributed to the advancements in the material sciences [1]. Zirconium dioxide (ZrO_2), or zirconia, is a white crystalline oxide of zirconium and has been used as a biomaterial since 1970s, mainly because of chemical inertness, resistance to corrosion, low bacterial affinity, esthetics and excellent biocompatibility. Pure zirconia, at atmospheric pressure is known to exhibit three crystal structures, Cubic (at temperatures > 2367 °C), Tetragonal (at temperatures from 2367 °C to 1167 °C) and Monoclinic (below 1167 °C) [2].

However the tetragonal to monoclinic (t → m) phase transition either induced by temperature variation or by stresses results in 3% to 5% of volumetric expansion that can cause it to crack during cooling. Incorporating 3 to 5 mol% of Yttria (Y_2O_3) stabilizes the core ceramic referred to as Yttria-stabilized Tetragonal Zirconia Polycrystals (Y-TZP). This strengthens and toughens the zirconia structure thereby inhibiting the potential for the propagation of crack. This property of Transformation Toughening, enables it to be popularly known as "Ceramic steel" [3].

Despite its high Strength and superior mechanical properties, low wettability and Hydrophobic nature of the zirconia surface interferes with adequate bonding, thereby resulting in reduced bond strength between the zirconia and the cementing material. Moreover the absence of silica phase or the glassy phase makes it chemically stable and much more resistant to acid etching. The focus has been towards improving the bonding between the veneering material and the zirconia [3]. Apart from the inherit hydrophobic nature and its low wettability, the contamination of the surface with saliva, blood and silicone disclosing agents further reduce the composite to ceramic bond strength [4].

Various treatment modalities have been employed to enhance the adhesion between zirconia and the veneering material by altering its surface dynamics, some of which includes, airborne particle abrasion, tribochemical silica coating, functional silane monomer application, phosphate primer application, vitrification, silica nanoparticle surface deposition, Non thermal argon plasma [5], Sandblasting, Er:YAG or Nd:YAG laser surface treatment and selective infiltration etching [6].

Sandblasting, or Air borne abrasion with silica coated alumina particles improves the micromechanical retention by increasing the surface roughness thereby increasing the surface reactivity. However this is also associated with the formation of microcracks which would influence the long term performance of the restoration [7].

Plasma is a partially or a fully ionised gas and is considered to be the fourth state of matter. The interaction of Plasma with various types of materials, termed as Plasma Surface Modification (PSM) results in either the removal or organic debris, cross-linking via activated species, ablation, or altering the surface chemical structure. Nonthermal Argon plasma surface treatment increases the surface energy by decreasing the surface carbon content and increasing oxide polar groups, which improves the hydrophilicity of the surface resulting in improved wetting and better adhesion between the restoration and the substrate [8].

Zirconia surface treatment with Er:YAG has been shown to improve their bonding to the tooth structure [6,9,10], however the results are contradictory in a few other studies [11].

The failure of the zirconia systems is seen commonly at the interface between the zirconia core and the veneered ceramic [12]. Hence this study aims to evaluate and compare the effects of Non thermal Argon plasma and Er:YAG surface treatment modalities on the Shear bond strength of veneering ceramic to zirconia.

A number of studies emphasise the combination of surface treatments to enhance the bond strength between the zirconia and the veneering material. However there are no studies reporting the combination of argon plasma with ER:YAG laser. The null Hypothesis of the study was that Er:YAG and Argon Plasma surface treatment of zirconia surface does not enhance the bond strength between the zirconia and the veneering material.

Method of Collection of Data

150 zirconia blocks with dimension 10mm width and 18mm height (Figure 1) were fabricated with presintered zirconia blank (Ceramill zi Low Translucency Zirconia, Amann Girrbach, Germany) (Figure 2) using CAD CAM (Ceramill motion 2) (Figure 3). Zirconium oxide blocks were milled according to the manufacturers' instruction.

Then, the samples were cleaned, dried, and sintered according to the suggested firing schedules (Figure 4). The bonding surfaces of zirconia core specimens was polished with diamond paste using an ascending stepwise approach starting with 120 grit and ending with 800 grit silicon carbide paper,120-,240-,320-,400-,600-, and finally 800-, using a rotating metallographic polishing device under a fixed load and water cooling. This was done to obtain standardized surface roughness.

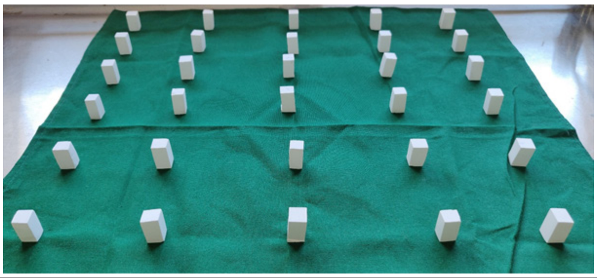

Figure 1

Figure 2

Figure 3

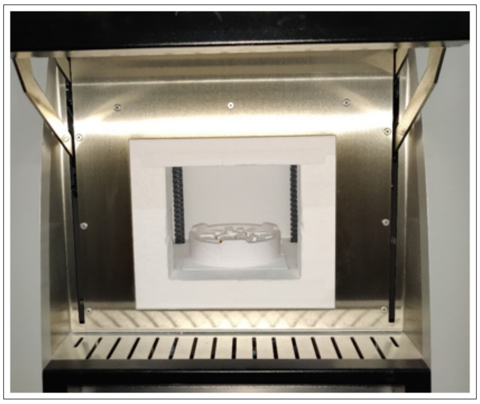

Figure 4

Surface treatment methods: 150 zirconia blocks were randomly divided into five groups according to the surface treatment methods:

Group 1: Argon plasma + Liner
After treatment with argon plasma as mentioned earlier, ceramic liner(e max ceram zirliner) application was done according to the manufacturers instructions.

Group 2: Atmospheric pressure plasma gas
Specimens were surface treated with plasma jet using argon gas for 30s. The operating conditions for the plasma treatment parameter (an electric voltage of 220 V and power of 100W, and constant gas pressure (1 kg/cm2) and gas flow 8.5L/min) (Plasma Cleaning System 102B) (Figure 5).

Group 3: Sand blasting
Al2O3 airborne-particle abrasion was performed using a sandblast machine with 50μm particle size for 15 seconds at a 10mm distance from the surface and with a pressure of 1.5 bar. Finally, the specimens were ultrasonically cleaned in 96% isopropyl alcohol for 3 minutes and steam-cleaned for 15 seconds (Figure 6).

Group 4 Sandblasting + Laser ablation + Argon plasma
After sandblasting the specimens according to the parameters mentioned above, Er:YAG pulsed laser was irradiated at the 2.94μm wavelength and 300mJ/pulse energy for 2 minutes, with a focal distance of 5mm and frequency of 10Hz. Intermittent cooling with air and water spray was used throughout the irradiation (Figure 7). The prepared discs were cleaned in an ultrasonic cleaner for 5 minutes and were steam-cleaned. Finally it was treated with Argon plasma as mentioned in the above group.

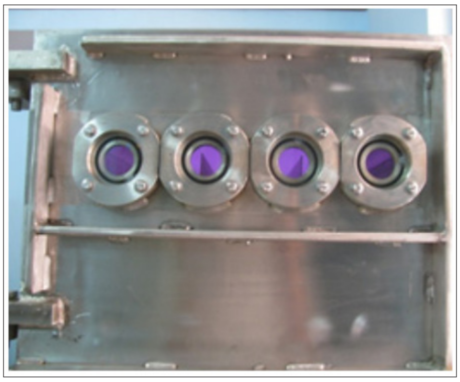

Figure 5

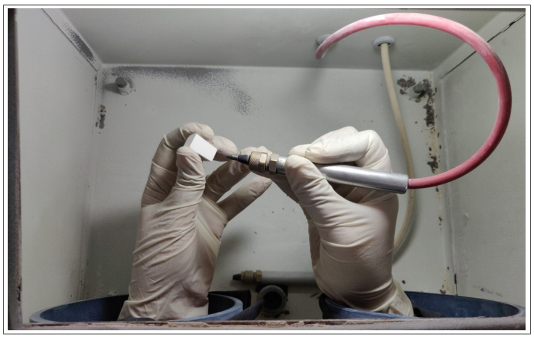

Figure 6

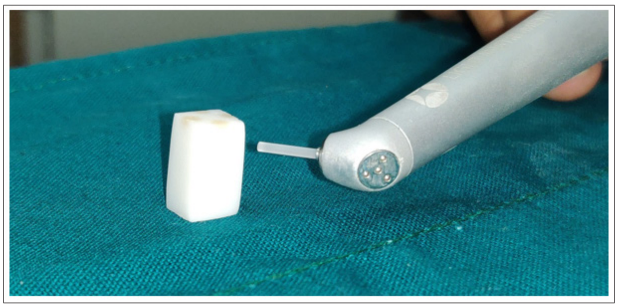

Figure 7

Group 5 Sandblasting + Argon plasma
Surface treatment for this group will be done according to the parameters mentioned in the previous groups.

Statistical Analysis
Data was analyzed using the statistical package SPSS 22.0 (SPSS Inc., Chicago, IL) and level of significance was set at p<0.05. Descriptive statistics was performed to assess the mean and standard deviation of the respective groups. Normality of the data was assessed using Shapiro Wilkinson test. Inferential statistics to find out the difference between and within the groups was done using ONE WAY ANOVA and TUKEYS HSD POST HOC TEST.

Results
Table 1 depicts the graphical representation of the mean and standard deviation of the values obtained for Shear Bond Strength for each of the group. Table 2 depicts descriptive data regarding the mean, standard deviation, minimum and maximum values obtained for each group.

Bond Strength In Megapascals (Mpa)

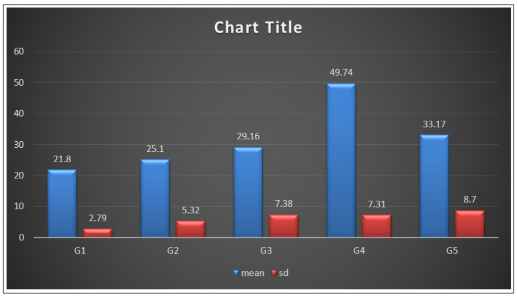

Table 2: Decriptive Data of Bond Strength

Group	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
GROUP I	30	21.80	2.79	0.23	21.81	28.4
GROUP II	30	25.10	5.32	0.11	17.9	36.12
GROUP III	30	29.16	7.38	0.06	29.16	45.44
GROUP IV	30	49.74	7.31	0.57	49.74	62.3
GROUP V	30	33.17	8.70	0.04	33.17	48.5

One-way ANOVA revealed that significant difference was there between the groups regarding the mean bond strength, i.e., P = 0.001 [Table 3]. The Tukey's Post hoc Bonferroni analysis was done to find out the significant difference between any of the two given groups. Result showed statistically significant difference between all the groups except between G1 VS G2(P>0.05), G2 VS G3(P>0.05) and G3 VS G5(P>0.05) [Table 4]

Table 3: Summary of Anova Statistics

	Sum of Squares	df	Mean Square	F	p value
Between Groups	14228.1600	4	3557.0400	83.546	0.0001*
Within Groups	6173.4330	145	42.574		
Total	20401.5930	149			

*P<0.05 is statistically significant (One Way Anova Test)

Table 4: Tukey's Hsd Posthoc Test (Pairwise Comparison)

Group (I)	Group (J)	Mean difference (I-J))	95% of confidence interval		P VALUE
			Lower	upper	
G1	G2	3.3	-1.3535	7.9535	0.2915
	G3	7.3	2.6465	11.9535	0.0003*
	G4	27.9	23.2465	32.5535	0.0001*
	G5	11.3	6.6465	15.9535	0.0001*
G2	G3	4	-0.6535	8.6535	0.1283
	G4	24.6	19.9465	29.2535	0.0001*
	G5	8	3.3465	12.6535	0.0001*
G3	G4	20.6	15.9465	25.2535	0.0001*
	G5	4	-0.6535	8.6535	0.1283
G4	G5	-16.6	-21.2535	-11.9465	0.0001*

*P<0.05 is statistically significant (Tukey's Post Hoc Test)

Mean shear bond strength is highest for the group sandblasting + Laser + Argon plasma (49.74) followed by the group Sandblasting + argon plasma (33.17), Sandblasting (29.16), Argon plasma (25.1) and the least for Argon plasma + Liner group (21.8) [Table 1]

SEM (Scanning Electron Microscope) results

The SEM image of (Sandblasting + Argon + Laser) [Figure 8] and (Sandblasting + Argon) [Figure 9] group reveal surface roughness as well as clean surface devoid of contaminants necessary for optimal bonding.

The image of Argon plasma + Liner [Figure 10] group reveal a relatively smooth and clean surface.

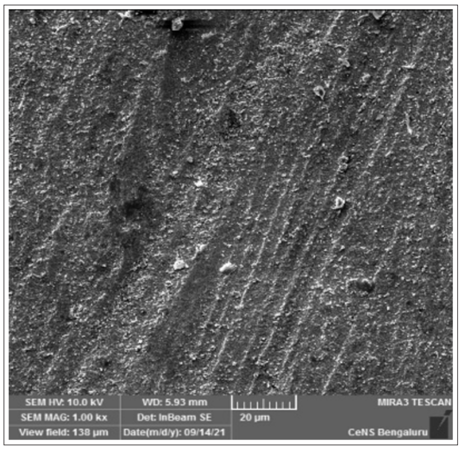

Figure 8: Sandblasting + Laser + Argon

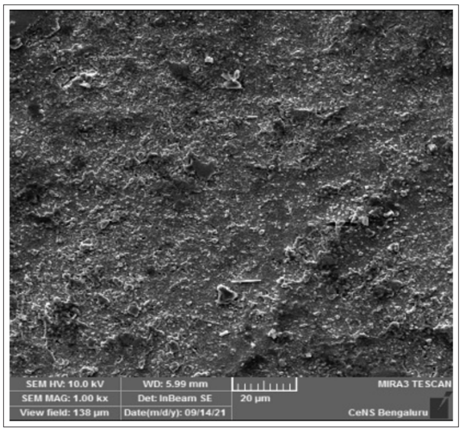

Figure 9: Sandblasting + Argon plasma

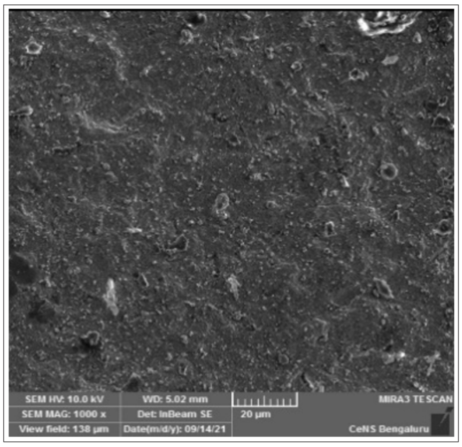

Figure 10: Argon plasma + Liner

Discussion

Yttria stabilised Zirconia are now being used to replace metal as the core structure because of its strength, aesthetics and biocompatibility. However, its relatively high refractive index increases the light reflection and compromises the translucency and therefore aesthetics. Hence a veneering material is often used to enhance the aesthetics when these core materials are used [13,14]. The adhesion of veneering ceramic to the zirconia substructure is limited mainly due to its hydrophobic nature and low wettability. The present study was designed to evaluate the effect of various surface treatments on the shear bond strength of veneering ceramic to the zirconia core.

The present study concluded that among the various surface treatments, the highest shear bond strength values were obtained for Group 4 (49.74 ± 7.31)
followed by group Group 5 (33.17 ± 8.7) > Group 3 (29.16 ± 7.38) > Group 2 (25.1 ± 5.32) > Group 1 (21.8 ± 2.79).

Sandblasting the specimens before sintering enhances the surface roughness and also ensures a larger surface area for the interaction of veneering ceramic improving the bond strength through mechanical interlocking [7,15]. Min HE et. al., in their study reported that the surface roughness, after sandblasting of pre-sintered zirconia blocks improved over 500% when compared to those after sintering [15]. Sandblasting was done with 50μm Al_2O_3 particles, for the specimens in Group 3, Group 4 and Group 5 which showed consistently higher values for the bond strength when compared to the first two groups where sandblasting was not done.

Apart from increase in the surface area, the surface cleanliness is an absolute prerequisite which directly influences the surface energy necessary for optimal bonding. Interaction between the ionised atoms and the zirconia surface results in the breakage of weak bonds that were previously stabilized by radicals thereby resulting in the formation of polar groups that improve the bonding [16]. Valverde et al. reported an improvement in the surface energy and decrease in the contact angle by around 50%, of the argon plasma treated specimens due to the formation of polar groups [17].

Surface treatment with Non-Thermal Atmospheric Argon plasma (NTAP) removes the surface contamination, enhances surface cleanliness and is said to produce a super-hydrophilic surface improving the interaction between the veneering ceramic and the core [18]. Christoph Piest et al. in their study concluded that surface pretreatment with argon plasma effectively removed the salivary contamination and the tensile bondstrength of surface treated specimens was higher when compared to that of non treated specimens [4].

Moreover the rougher surface may also act to encourage bacterial adhesion. Argon plasma surface treatment has the ability to modify the surface for improved bonding without affecting the surface roughness, and is also reported to inhibit the bacterial colonization on the surface post treatment [19,20]. The ability to inhibit the bacterial adhesion was evaluated by Chan Park et al., where after surface treatment with NTAP there was a significant reduction in the biofilm thickness, and also the number of viable micro-organisms [20].

In the present study surface treatment with argon plasma alone has proven to be less effective. However when combined with sandblasting the values obtained were higher than when sandblasting was used alone, but was not statistically significant. This improvement in the bond strength can be attributed to the enhanced surface cleanliness and improved hydrophilicity obtained through argon plasma surface treatment in addition to the properties obtained through sandblasting.

Er:YAG laser irradiation has been proven to enhance bond strength as effective
as sandblasting and few studies even report increased value for Laser
irradiation than sandblasting [12]. Er:YAG laser irradiation has proved to have the
mechanism of microexplosion and vaporisation creating surface roughness.

However, as this concept cannot be applied for the surface treatment of zirconia as it lacks a specific chromophore which is essential for the interaction of laser with surface. Thus, the probable mechanism could be the temperature change on application of laser that causes melting of superficial surface which hardens subsequently on cooling. This repeated melting and rehardening causes surface irregularities which improves the shear bond strength between zirconia to veneering ceramic [22].

Phase transformation from tetragonal to monoclinic is said to occur after airborne particle abrasion which was not seen in laser irradiation which helps in preserving structural integrity of zirconia. This would ultimately increase the longevity of bond between zirconia and veneering ceramic [21,22]. Studies however report deterioration of surface properties with higher power settings. Thus relatively lower power settings was used in the present study.

Omer Kirmali et al., in their study report, combination of surface treatment (Sandblasting + Laser), to show significant increase in bond strength than sandblasting or liner or laser used as a single mode of surface treatment [12].

Thus, in accordance with this study that states combination of surface treatments to enhance shear bond strength rather when used as a single surface treatment, the present study has also reported to show highest bond strength in Sandblasting + Laser + Argon plasma treated group.

This enhanced bond strength would be due to optimization of one surface property by the other, i.e., optimization of the surface property obtained through sandblasting by argon plasma and laser irradiation thus acting synergistically to improve the bond strength.

The application of liner as a surface treatment is however controversial with most studies suggesting the application of liner to have negative effect on the bond strength [23,24]. Pulici Carlos et al., reported a significant reduction in the bond strength between the zirconia and veneered ceramic after coating with Zirliner [25]. This could be due to formation of layer or an interface that would significantly affect bonding [26]. The present study also reported reduced bond strength values after the application of liner, suggesting that liner application could significantly affect the bonding between the zirconia and the veneering ceramic.

Conclusion

Within limitations of the present study, the following conclusions can be drawn:

1. Argon plasma surface treatment alone is a less effective way of improving bond strength between zirconia and veneering

ceramic.

2. Sandblasting, Er:YAG laser irradiation followed by Argon plasma decontamination of the surface is an effective combination surface treatment for enhansing bond between zirconia and veneering ceramic.

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