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Veneer Ceramic to Y-TZP Bonding: Comparison of Different Surface Treatments

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Keywords
Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP); zirconia restorations; veneering ceramics; surface treatments; dental lasers; shear bond strength; Er-Cr:YSGG laser; SEM.

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Abstract

Purpose: The purpose of this study was to evaluate the effects of various surface-treatment techniques for enhancing the bond strength between veneering ceramic and yttria-stabilized tetragonal zirconia polycrystals (Y-TZP).
Materials and Methods: Pre-sintered Y-TZP specimens were divided into eight groups (n = 10) according to the surface-treatment technique used: (a) untreated (control); (b) air abrasion with aluminum oxide particles; (c) erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser irradiation at different energy intensities (1 to 6 W). All specimens were then sintered and veneered with veneering ceramic according to the manufacturer's instructions. The obtained zirconia-ceramic specimens were immersed in 37°C distilled water for 24 hours before a shear bond strength test using a universal testing device at a 1 mm/min crosshead speed. The average values were calculated. After debonding, the Y-TZP surfaces were examined under a stereomicroscope to determine their fracture pattern, and the surface topography was evaluated with scanning electron microscopy after surface treatments.
Results: The bond strength ranged from 13.24 to 20.54 MPa. All surface treatments increased the bond strength between the veneering ceramic and Y-TZP; however, the value for the 6 W irradiation group was significantly different from the values for other groups ($p < 0.05$).
Conclusions: The present study's findings showed that higher energy densities were needed for the laser irradiation to improve the bond strength between the veneering ceramic and zirconia. *Clinical Implication*: Y-TZP is commonly used as a core material in fixed restorations. The bond strength between zirconia and the veneering ceramic can be affected by various surface treatments.

Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) are highly attractive compared to other dental ceramics because of their superior mechanical properties, such as high flexural strength (700 to 1200 MPa) and fracture toughness (7 to 10 MPa $m^{1/2}$), and their esthetic properties.[1,2] It is the material preferred by dentists for many dental applications and has been used as a core material for single crowns,[3] frameworks for fixed partial dentures (FPDs),[4] orthodontic brackets, and implant abutments.[5,6]

Zirconia has three crystal structures: monoclinic (m) at low temperatures, tetragonal (t) above 1170°C, and cubic (c) above 2370°C. After firing, the t-m phase transformation occurs during cooling, and the crystal changes from a tetragonal structure to a monoclinic structure, resulting in a volume increase of 3% to 5%. If the phase transformation cannot be controlled, some cracks and fractures can form because of the compressive stresses in the lattice.[2,6]

Y-TZP is a material with a strengthened substructure, and it must be covered with a semitransparent veneering ceramic to attain an esthetic appearance.[7] Effective bonding relies on the micromechanical interlocking between zirconia and the veneering ceramic, which is a very important factor for the long-term success of zirconia restorations. Unlike Y-TZP, a veneering ceramic does not have good mechanical properties, and the lack of strong bonding at the interface between zirconia and the veneering ceramic may result in fractures in clinical application.[8] Aboushelib et al[9] stated that Y-TZP substructures have the lowest connection resistance. Similarly, Conrad et al[10] reported that fracturing in a zirconia restoration begins in the weakest area of the interface between the Y-TZP substructure and the

veneering ceramic. Some researchers have reported fracturing rates of 13% for veneering ceramics at the end of 3 years,[11] 25% for zirconia with veneering ceramics at the end of 31 months,[4] and 5% for the DC-zirconia substructure in veneering restorations at the end of 2 years.[5]

Factors affecting bond strength include the thermal coefficient of ceramic materials, surface defects or improper support by the framework, low fracture toughness of the veneering porcelain, and low thermal conductivity of zirconia.[4,5,7,9,11] Therefore, to increase the bond strengths of veneering ceramics, several surface treatment procedures on zirconia have been developed.[12,13] According to the results, some treatments are not suitable for high-strength ceramics like Y-TZP. One of these treatments is acid etching because it does not produce a glassy phase.[14] Alternative treatment techniques have thus been used, especially air abrasion of the zirconia surface with aluminum oxide (Al_2O_3) particles. Investigations[15,16] on the effect of different particle sizes (25 to 250 μm) of Al_2O_3 have shown that air abrasion increases the surface area for bonding and removes loose contaminated layers.

On the other hand, with the development of dental lasers, some researchers have evaluated their effects, commonly using erbium:yttrium-aluminum-garnet (Er:YAG),[12,17] neodymium:yttrium-aluminum-garnet (Nd:YAG),[14,18] carbon dioxide (CO_2),[19] and erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG)[20,21] lasers for various clinical applications such as reducing tooth sensitivity, bleaching, removing caries, and roughening a ceramic surface. The Er,Cr:YSGG laser can remove particles through a process called ablation, which includes micro-explosions and vaporization.[22] In vaporization, the internal pressure builds within the ceramic until the explosive destruction of inorganic substance occurs before the melting point is reached.[20] Some studies[20,21] have evaluated the effects of Er,Cr:YSGG laser irradiation on the shear bond strength of resin cement to ceramic restorations; however, a review of the literature found no study evaluating the effect of Er,Cr:YSGG laser irradiation on Y-TZP. The purpose of this study was to evaluate the effects of various surface-treatment techniques (air abrasion and laser irradiation at different intensities) for enhancing the bond strength between the veneering ceramics and Y-TZP. The null hypothesis was that the employment of surface treatments would increase the bond strength.

Materials and methods

Zirconia specimens (diameter: 7 mm; height: 3 mm) were fabricated from unsintered blocks (Noritake Co., Nagoya, Japan) and polished under water with 600-, 800-, and 1200-grit silicon carbide abrasives (English Abrasives, London, UK), using a sanding machine (Phoenix Beta Grinder/Polisher; Buehler, Düsseldorf, Germany) to create a standard surface. All zirconia specimens were randomly divided into eight groups (n = 10) (Fig 1) according to the surface treatments performed:

Control group: Specimens in the control group were not treated.

Air-abrasion group: Specimens were subjected to air abrasion with 120-μm Al_2O_3 particles for 15 seconds at 2-bar pressure from a distance of 10 mm.

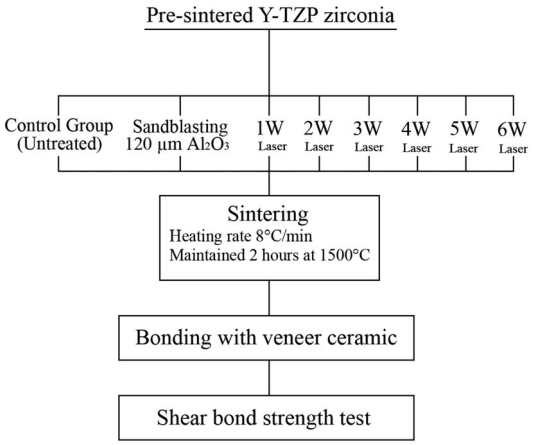


Figure 1 Schematic representation of test protocol.

Laser groups: All the surfaces of the specimens were subjected to Er,Cr:YSGG laser irradiation (Millenium, Biolase Technology, San Clemente, CA) with a wavelength of 2.78 μm, pulsed laser-powered hydrokinetics, a repetition rate of 20 Hz, and a beam energy intensity of 1, 2, 3, 4, 5, or 6 W. Water and air flows of 55% and 65%, respectively, were used continuously during the 20-second irradiation. The optical fiber of the laser (diameter: 600 μm; length: 6 mm) was placed perpendicular to the surface at a distance of 10 mm.

After the surface treatments were completed, all (both untreated and treated) specimens were sintered at 1500°C for 8 hours in a ZYrcomat (VITA Zahnfabrik, Bad Sackingen, Germany) sintering furnace in accordance with the manufacturer's recommendations. Porcelain veneers were applied on the zirconia surface using a cylindrical mold (diameter: 5 mm; length: 3 mm) according to the manufacturer's instructions (Fig 2). They were fired in a vacuum porcelain furnace that could be programmed to 760°C. All specimens were then cleaned ultrasonically with distilled water for 3 minutes and stored in distilled water at 37°C for 24 hours. The zirconia-ceramic specimens were then submitted to a shear bond strength test using a universal testing machine (Lloyd LF Plus; Ametek Inc., Leicester, UK), with a 1 mm/min crosshead speed until fracture. The surfaces of the fractured specimens were analyzed under a stereomicroscope (Stemi DV4; Carl Zeiss, Göttingen, Germany) at 32× magnification to assess the failure type. The observed failure modes were adhesive failure, in which the veneering ceramic completely separated from the zirconia surface; cohesive failure, in which the veneering ceramic completely fractured; and mixed failure, in which both failure types were observed (adhesive and cohesive).

The differences in the values of bond strength between the zirconia and veneering ceramic were evaluated with ANOVA and pairwise comparisons using the Tukey post-hoc test. The data were analyzed using the SAS 9.1 statistical package (SAS Institute, Cary, NC). The test was performed at a significance level of 0.05.



Figure 2 (A) Zirconia specimen was placed into the bottom end of the cylindrical mold. (B) Veneer application on zirconia surface. (C) Zirconia-ceramic specimen before bond strength test.

Table 1 Mean (MPa) and standard deviation values of the bond strength and incidence of failure modes

			Failure types Mean (SD)		
Groups	*n*	Mean (SD)	Adhesive	Cohesive	Mixed
Control	10	13.24 (2.11)[a]	6	0	4
Air abrasion	10	15.98 (3.98)[a]	4	0	6
1 W laser	10	14.10 (6.48)[a]	5	1	4
2 W laser	10	15.31 (3.84)[a]	3	1	6
3 W laser	10	15.57 (4.11)[a]	6	0	4
4 W laser	10	17.78 (5.08)[a]	6	1	3
5 W laser	10	18.52 (2.04)[a]	7	1	2
6 W laser	10	20.54 (6.66)[b]	4	0	6

Means with the same letters were not significantly different. SD: standard deviation.

Scanning electron microscope analysis

Randomly selected specimens from all groups were mounted on metallic stubs, sputter-coated with gold, and evaluated for topographical differences with a scanning electron microscope (SEM; JSM-6060LV, JEOL, Tokyo, Japan). The zirconia surfaces were examined before and after sintering. Images from each group were taken at 1000× magnification and an accelerating voltage of 20 kV.

Results

Table 1 presents the values of the mean and standard deviation of the bond strength for all specimen groups. The eight groups, in decreasing order of their mean bond strength, were the 6 W, 5 W, and 4 W irradiation groups; the air abrasion group; the 3 W, 2 W, and 1 W irradiation groups; and the control group. The mean values of the shear bond strength of the control group and 6 W irradiation group were significantly different ($p < 0.05$); however, the differences in the mean shear bond strength among other groups (control, air abrasion, 1 W, 2 W, 3 W, 4 W, and 5 W irradiation) were not statistically significant ($p > 0.05$).

An analysis of the failures revealed that fracturing occurred predominantly in the adhesive at the veneering/ceramic/zirconia interface (51.25% of the failures). Mixed failures (adhesive and cohesive) were less prevalent (43.75% of the failures), and cohesive failures in the veneering ceramic were infrequent (5% of the failures).

Figures 3 and 4 show the SEM images of pre- and post-sintering surfaces of specimens subjected to different surface treatments. The specimen from the control group had a typical untreated zirconia surface. In the images of all the experimental groups, deeper crevices, small pits, and micro-cracks were observed on the pre-sintering zirconia surface. In turn, more surface irregularities were observed on the pre-sintering zirconia surface in the 6 W irradiation group than in the other groups. After sintering, a tighter structure was observed in the surface roughness. The SEM images support the values obtained for the shear bond strength of all groups.

Discussion

Some studies[9,12] have evaluated the surface roughness and bond strength between the zirconia and resin cement or veneering ceramic after various surface treatments on zirconia. Effective bonding is necessary to ensure longevity of the zirconia restoration; otherwise, there will be fractures in clinical application, as demonstrated by long-term results.[4,5,11] To eliminate this failure, researchers aim to improve the bond strength by increasing the surface area on zirconia through different surface treatments. It has been reported that post-sintering surface treatments increase the fracture risk by, for example, weakening the structure of Y-TZP and accelerating the t-m transformation, and damage zirconia by increasing the fraction of the monoclinic phase.[23-26]

Pre-sintering surface treatments on the zirconia surface have been recommended for enhancing Y-TZP's mechanical properties by increasing the fraction of the tetragonal phase.[25,26] In addition, it has been reported that pre-sintering surface treatments on Y-TZP increases the bond strength by creating a retention area on the surface. Therefore, the focus of the present study was to investigate the effect of air abrasion and Er,Cr:YSGG laser irradiation (at different intensities) on the bond strength of Y-TZP prior to sintering. Our results validated the null hypothesis, as laser irradiation increased the bond strength.

Air abrasion with Al_2O_3 particles is a common technique in the surface treatment of ceramic materials. In addition to removing the contamination layers on zirconia, air abrasion is used to prepare a rough surface to facilitate strong adhesion of veneering ceramics or resin cement.[13,14,27] However, conflicting results for post-sintering treatments on a zirconia surface have been reported in the literature. Fischer et al[28,29] reported that air abrasion was not a necessary surface treatment for bond strength improvement. On the contrary, Kim et al[30] found that air abrasion produced stronger bond strength values.

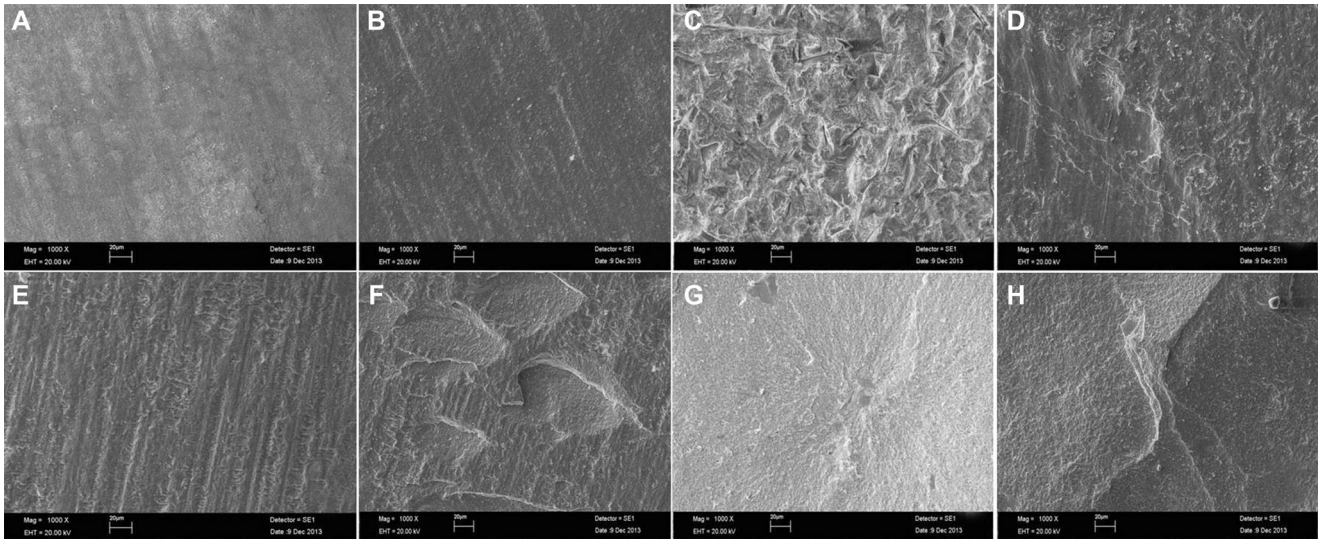


Figure 3 SEM images from zirconia surfaces treated with different techniques (1000×): (A) no treatment pre-sintered zirconia, (B) after sintering zirconia, (C) sandblasted pre-sintered zirconia, (D) after sintering zirconia, (E) 1 W laser irradiation pre sintered zirconia, (F) after sintering zirconia, (G) 2 W laser irradiation pre-sintered zirconia, (H) after sintering zirconia.

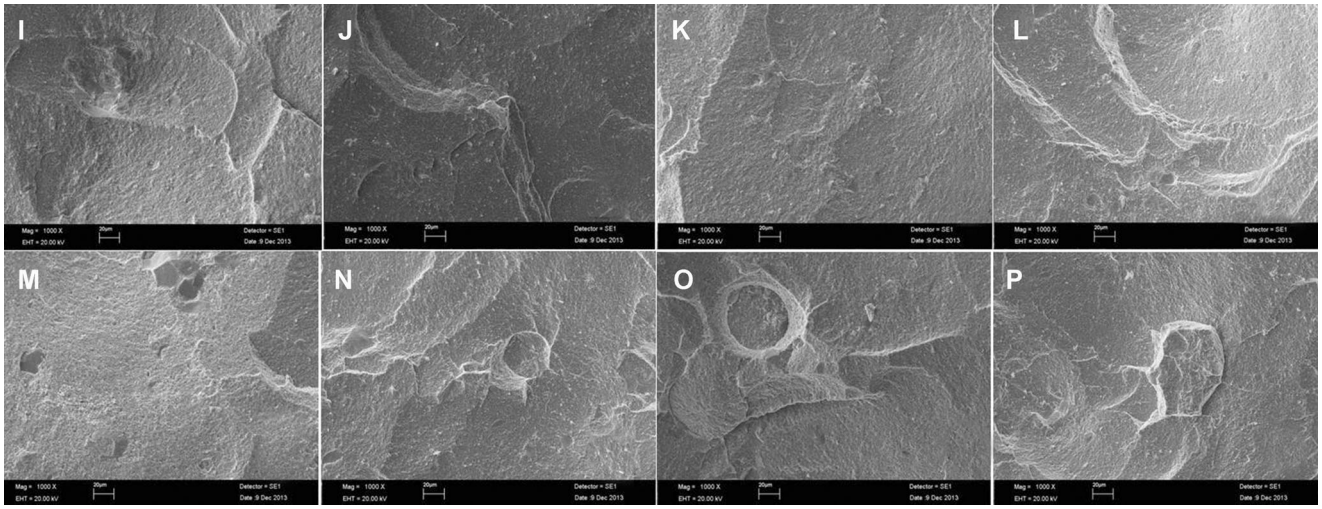


Figure 4 SEM images from zirconia surfaces treated with different techniques (1000×): (I) 3 W laser irradiation pre-sintered zirconia, (J) after sintering zirconia, (K) 4 W laser irradiation pre-sintered zirconia, (L) after sintering zirconia, (M) 5 W laser irradiation pre-sintered zirconia, (N) after sintering zirconia, (O) 6 W laser irradiation pre-sintered zirconia, (P) after sintering zirconia.

Similarly, Aboushelib et al[9] obtained the highest bond strength value after air abrasion of zirconia with Nobel Rondo as the veneering ceramic. These two research groups[9,30] evaluated the bond strength between zirconia and the veneering ceramic by using post-sintering surface treatments.

When compared with other treatments, air abrasion before sintering has increased the bond strength values between zirconia and resin cement.[25,26] A zirconia surface with higher wettability has been recommended as it leads to higher surface roughness. On the other hand, Kirmali et al[12] examined the effects of different pre-sintering treatments on the bond strength between zirconia and the veneering ceramic and found that when compared with untreated zirconia, the air-abraded surface had increased bond strength values. Similarly, in the present study, air abrasion resulted in higher bond strength, but the differences were not statistically significant.

Dental lasers have been used in various clinical applications, such as cavity preparation, reducing tooth sensitivity, bleaching, removing caries, and root canal procedures. Some researchers[12,14,19,20] have used dental lasers (Er:YAG, ND:YAG, CO_2, and Er,Cr:YSGG lasers) to evaluate their effects on a ceramic surface; however, there is limited knowledge on the effects of laser etching on dental ceramics, and conflicting results have been observed.

Cavalcanti et al[22] investigated the effects of a metal primer, resin cement, and a combination of surface treatments (untreated, air abrasion with Al_2O_3 particles, and Er:YAG laser irradiation) on zirconia surfaces; they reported that the surface treatments significantly affected the bond strength to zirconia. Another study[31] showed that compared to other treatments, Er:YAG laser irradiation at 600 mJ significantly affected the surface roughness. Demir et al[32] found that Er:YAG laser irradiation at different intensities increased the surface roughness on a sintered zirconia surface; however, Cavalcanti et al[31] reported that higher laser-power settings may cause heat damage to the zirconia structure. Gökçe et al[33] reported that while melting areas, deeper crevices, and excessive loss of mass were observed in zirconia subjected to post-sintering treatments, the same phenomena were also detected in ceramics subjected to surface treatment prior to sintering. In this study, however, no significant loss of structure was observed on the zirconia surface because pre-sintering surface treatments were applied, and the zirconia was less hard and chalk-like before it was sintered.

Akın et al[27] reported that irradiation with Nd:YAG, Er:YAG, and Nd:YAG lasers in the contact mode resulted in statistically higher bond strength values than those obtained for other specimen groups. Similarly, Spohr et al[14] reported that surfaces irradiated with a Nd:YAG laser had increased bond strength. Ural et al[19] evaluated the effects of different surface treatments and CO_2 laser irradiation on the shear bond strength of resin cement to zirconia, and they found that the highest bond strength values were obtained with laser irradiation.

In contrast to these studies, Akyıl et al[34] reported reduced bond strength in zirconia specimens irradiated by a Nd:YAG laser group and specimens subjected to a combination of air abrasion and Er:YAG laser irradiation, while the bond strength values increased with Er:YAG laser irradiation and a combination of air abrasion and Nd:YAG laser irradiation. Moreover, Foxton et al[35] suggested that Er:YAG laser irradiation does not create a durable bond between resin cement and zirconia, which does not agree with the conclusions of Kırmalı et al,[12] who obtained the highest bond strength value prior to sintering of zirconia treated with air abrasion and irradiation by an Er:YAG laser. In the present study, all surface treatments increased the bond strength values, but there was a statistically significant difference only between the results of 6 W irradiation and other treatments.

Cavalcanti et al[22] and Akın et al[27] examined the bonding between zirconia and resin cement after different surface treatments, and they reported that adhesive failure was more common than the other failure types, which is similar to the results of the failure analysis in the present study.[22,27] To evaluate the effect of temperature changes in the mouth on bonding at the zirconia/veneering-ceramic interface, thermocycling tests may be necessary for clinical trials.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The highest bond strength value was recorded in the 6 W irradiation group (20.54 ± 6.66 MPa), and the lowest value was recorded in the control group (13.24 ± 2.11 MPa).
2. 6 W laser irradiation of the zirconia surface prior to sintering was the most effective surface treatment for increasing the bond strength between zirconia and the veneering ceramic.
3. Similar bond strength values were obtained after air abrasion and irradiation by an Er,Cr:YSGG laser at 1 to 5 W.
4. 4 W and 5 W laser irradiations resulted in higher bond strengths than that of the untreated surface, but the differences were not statistically significant.

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