Original Article

Effects of Different Surface Treatments on Shear Bond Strength and Surface Roughness of Zirconia Bonded to Composite Resin

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KEY WORDS
Yttria;
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ABSTRACT

Background: With increasing demand for metal-free restorations, yttria-stabilized tetragonal zirconia polycrystal has become a preferred material for ceramic crowns, bridges, and other restorative dental procedures. Mechanical and laser treatments, including diamond bur grinding and laser irradiation can improve bond strength to zirconia, although there are controversies regarding their effectiveness.

Purpose: We aimed to evaluate the effects of three different surface treatment types, mechanical (diamond bur grinding), laser, and combined treatments, on the shear bond strength and surface roughness of zirconia.

Materials and Method: In this *in vitro* study, sixty yttria-stabilized tetragonal zirconia polycrystal specimens were prepared and divided into six groups, including a control group (standard polishing), as well as groups undergoing diamond bur, and/or laser irradiation. Specimens were treated with silane and bonded with composite resin before testing. Surface roughness was assessed using a profilometer. Bond strength was tested using a universal testing machine.

Results: The highest bond strength was observed in the diamond bur group (354.30 MPa), while the lowest was in the control group (159.50 MPa) (*p* Value< 0.001). Surface roughness also varied significantly among groups, with the diamond bur group showing the highest roughness values. Bur-laser-treated groups showed increased roughness compared to laser-only treatments.

Conclusion: This study found that combining mechanical and laser treatments significantly improved the shear bond strength and surface roughness of zirconia compared to control and laser-only groups. Such combinations may improve the longevity of zirconia restorations. Future research should explore long-term durability and optimize treatment parameters.

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Introduction

With increases in aesthetic expectations and advancements in natural appearance, biocompatibility, and metal-free restorations, the use of all-ceramic restorations has been increasing [1]. This increase has prompted research into ceramic materials with enhanced mechanical properties, such as alumina and zirconia-based ceramics [2]. Zirconia has been as a material of preference in restorative dentistry with its high strength, durability, and improved aesthetics [3]. Its metal-free composition also reduces risks associated with metal-ceramic restorations, such as chemical toxicity and corrosion [3]. Consequently, the use of all-ceramic crowns has significantly increased in recent years [2].

Yttria-stabilized tetragonal zirconia polycrystal is favored because of its high fracture toughness, improved flexural strength, and favorable aesthetic properties [4]. The advent of computer-aided design/computer-aided manufacturing technology has reduced the process of fabrication, and zirconia restorations are now cost-effective and highly reproducible [5]. Zirconia exists in three crystalline forms- monoclinic, tetragonal, and cubic- with the tetragonal phase being stabilized at room temperature by the addition of yttria [6]. Despite these mechanical advantages, zirconia restorations require veneering for optimal aesthetics, a procedure which can sometimes lead to chipping and increased wear of the opposing dentition [7].

Achieving long-term adhesion between zirconia and resin cement is a critical factor for the clinical success of these restorations. Other conventional chemical treatments such as silanization and etching by hydrofluoric acid have minimal action on zirconia since it lacks a glassy phase [8]. Thus, both micromechanical and chemical approaches are essential for a durable bond. Micromechanical retention is enhanced by surface roughening, while chemical bonding is achieved through the use of zirconia primers that contain phosphate monomers such as 10-methacryloyloxydecyl dihydrogen phosphate. Mechanical and laser treatments therefore have been utilized to enhance micromechanical retention to its maximum. Methods like diamond bur grinding and airborne particle abrasion with aluminum oxide have been discovered to increase the surface roughness and induce micro-retentive features essential for bonding [9]. However, there is conflicting evidence regarding the optimal parameters for these mechanical treatments and their potential to induce structural defects.

Laser irradiation with modalities such as neodymium-doped yttrium aluminum garnet (Nd:YAG) and erbium-doped yttrium aluminum garnet (Er:YAG) represents an alternative approach for surface modification. However, their effect on surface roughness and bond strength remains highly controversial due to the wide range of energy parameters and exposure times [10]. A study reported that lasers can enhance bond strength by creating an irregular, molten surface, while others indicate that the intense heat can cause microcracks and phase transformation, which subsequently can weaken the bond [10]. This conflicting evidence creates a significant clinical dilemma regarding the most effective and safe method for preparing zirconia surfaces.

Previous research has determined that while mechanical treatments can lead to increased bond strengths due to heightened surface roughness, laser treatments alone may not always have the same effect [11]. In addition, treatments like sandblasting [12] and diamond bur grinding [13] can alter the surface properties without a negative effect on the mechanical properties of zirconia. Based on these controversies and the need for a clear evidence-based protocol, the present study aimed to comprehensively investigate the effects of different surface treatments, specifically mechanical, laser, and their combination, on the shear bond strength and surface roughness of zirconia.

Materials and Method

The materials used in this *in vitro* study included yttria-stabilized zirconia blanks (AIDITE-Wieland-98*14-HT-APW981403HTW), diamond burs with red and blue bands (D-Z Germany, ISO 199/Eur 850/L: 10mm), Universal Single Bond, Z250 composite, silane (Zprime), and silicon carbide abrasive papers with grit sizes of 600, 800, and 1200, which were used for standardizing the surface of the zirconia specimens using a polishing machine.

The equipment utilized in the study comprised an Nd:YAG laser (Pluser), an Er:YAG laser (Pluser), a laser handpiece, a computer-aided design/computer-aided manufacturing system for preparing zirconia specimens, a profilometer (Hommlewerke T8000 stylus profilometer) for surface roughness measurement, light-curing unit, universal testing machine for shear bond strength testing, and a digital caliper for measuring specimen dimensions. We used these methods as the most common and clinically relevant approaches for zirconia surface modification. By selecting these specific treatments, we aimed to address the practical clinical dilemma that dental practitioners face when choosing the optimal method for preparing zirconia restorations.

Partially sintered zirconia blanks (AIDITE) were obtained and processed using a computer-aided design/ computer-aided manufacturing to prepare the zirconia specimens. Initially, a circular zirconia blank with a diameter of 98 mm and a thickness of 14mm was sectioned into rectangular specimens measuring 6×11×11 mm. The exact dimensions were verified using a digital caliper. A total of 60 zirconia specimens were prepared and randomly assigned to six experimental groups (n=10 per group) using a computer-generated random number sequence.

To ensure uniformity across all specimens, a standardized polishing procedure was applied to all 60 zirconia specimens. Polishing was carried out using a polishing machine with silicon carbide abrasive papers (600, 800, and 1200 grit) at a speed of 300 rpm with water cooling and an applied force of 15 N for 15 seconds per sample. The specimens were then cleaned in an ultrasonic bath containing distilled water, followed by immersion in 100% ethanol for one minute, and subsequently air-dried.

The specimens were divided into six groups:

Group 1 (SP): Standard polishing with no additional surface treatment.

Group 2 (PL1): Standard polishing followed by surface grinding using an Nd:YAG laser.

Group 3 (PL2): Standard polishing followed by surface grinding using an Er:YAG laser.

Group 4 (PB): Standard polishing followed by grinding with a diamond bur and turbine under water cooling.

Group 5 (PBL1): Standard polishing followed by grinding with a diamond bur and an Nd:YAG laser. Surface grinding was performed with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Nd:YAG laser irradiation.

Group 6 (PBL2): Standard polishing followed by grinding with a diamond bur and an Er:YAG laser. Surface grinding was performed with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Er:YAG laser irradiation.

The Nd:YAG and Er:YAG laser treatments were performed with the following parameters: 2W output power, 20 Hz frequency, 2-minute exposure time, 100 µs pulse duration, 124.40 J/cm² energy density, perpendicular irradiation angle, 100mJ pulse energy, and 1 mm working distance. After surface treatments, all specimens were cleaned in an ultrasonic bath containing distilled water, immersed in 100% ethanol for one minute, and then air-dried.

Subsequent to surface treatment, a thin layer of Zprime silane was applied to all samples and kept for 30 seconds, followed by gentle air drying. Then, universal single bond was applied and light-cured from a 1mm distance for 20 seconds using a light-curing unit. A mold measuring 2×2×4 mm was used to layer the Z250 composite onto the treated zirconia surfaces in two increments. Each increment was light-cured for 20 seconds. After removing the mold, the entire composite structure was additionally light-cured for 60 seconds. The intensity of the light-curing unit was periodically verified using a radiometer. The bonded samples were then shaped using a high-speed turbine and stored in distilled water at 37°C for 72 hours before shear bond strength testing. This specific cleansing-and-bonding protocol was adopted to ensure a standardized and clinically relevant method for all groups, allowing for a consistent comparison of the effects of the different surface treatments on bond strength.

Shear bond strength testing was conducted using a universal testing machine (SANTAM-STM-50/IRAN). The crosshead speed was set at 0.5 mm/min, and the maximum force required to debond each sample was recorded. The load was applied parallel to the bonded interface and as close as possible to the composite-zirconia junction to ensure a pure shear stress. After shear bond strength testing, the debonded surfaces were examined under a stereomicroscope to determine the failure mode. Failures were classified as adhesive (at the zirconia-composite interface), cohesive (within the composite or zirconia), or mixed.

The surface roughness of the zirconia specimens was assessed using a profilometer (Hommlewerke T8000 stylus profilometer). The profilometer was calibrated before measurements. The evaluation was performed for all six experimental groups, measuring the mean surface roughness (Ra) and the mean surface profile height (Rz). For each specimen, three surface roughness measurements were recorded at different positions along an 11-mm transverse length. The probe moved at a speed of 0.5mm/s, and the mean values of Ra and Rz were calculated for each specimen.

The surface roughness and shear bond strength data were obtained from 60 specimens. The Kruskal-Wallis test was used to assess the distribution among the groups. Subsequently, post-hoc analysis was performed using Tukey's test to determine statistically significant differences between the groups. All statistical analyses were performed with the significance level set at $\alpha = 0.05$.

Results

The overall bond strength ranged from 103 MPa to 480 MPa, with an overall mean of 219.58 MPa (standard deviation= 83.16). The highest bond strength was observed in the PB group (mean= 354.30MPa, standard deviation= 94.66), while the lowest was recorded in the SP group (mean= 159.50 MPa, standard deviation= 33.01) (Table 1). There was a significant difference between the different surface treatment groups in terms of shear bond strength (*p* Value< 0.001).

The PB group had significantly higher shear bond strength compared to the SP, PL1, and PL2 groups (*p*< 0.001). In addition, PBL1 demonstrated significantly higher bond strength than SP (*p*= 0.004), and PBL2 showed a significant higher value compared to SP (*p*= 0.037). Moreover, PBL2 had significantly lower shear bond strength compared with PB (*p*= 0.005). The PBL1 also showed a significant lower shear bond strength than PB (*p*= 0.037).

The overall Ra and Rz mean (standard deviation) values were 1.47 µm (0.65) and 7.76 µm (3.68), respectively. The highest Ra value was observed in the PB group (2.20±0.51µm), while the lowest was in the SP group (0.88±0.29µm), Regarding Rz values, the highest was in the PB group (13.21±3.24 µm), while the lowest was in the SP group (5.36±1.59µm) (Table 2). There were significant differences in Ra (*p*< 0.001) and Rz between the groups (*p*< 0.001).

Pairwise comparisons revealed a significant higher Rz values in the PBL1 group than the PL2 group (*p*< 0.001), the SP group (*p*= 0.001), and the PL1 group (*p*= 0.001). Also, the PB group had significantly higher Rz values compared to the PL2 group (*p*< 0.001), the SP group (*p*< 0.001), and the PL1 group (*p*< 0.001). Also, the PBL2 group showed significantly lower Rz values compared with the PB group (*p*= 0.001) and the PBL1 group (*p*= 0.021) (Table 3).

The analysis revealed significant differences in Ra values among various treatment groups. The PBL2 and PBL1 groups exhibited significantly higher roughness compared to the SP (*p*< 0.001 and p= 0.001, respectively). Similarly, the PB group showed greater roughness than the control (*p*< 0.001). Comparisons among laser-treated groups indicated that PBL2 had significantly higher Ra values than the PL2 (*p*< 0.001), while PBL1 also demonstrated greater roughness than PL2 (*p*< 0.001). In addition, the PB group had significantly higher Ra values than the PL2 (*p*<0.001) and the PL1 (*p*< 0.001). A significant difference was also observed between the PBL1 and the PL1, with PBL1 displaying great-

Table 1: Mean and standard deviation of shear bond strength across different surface treatments

Group	Sample Size (n)	Mean (MPa)	Standard Deviation (MPa)
SP	10	159.50	33.01
PL1	10	195.20	86.98
PL2	10	190.30	29.51
PB	10	354.30	94.66
PBL1	10	214.50	19.43
PBL2	10	203.70	19.39

SP (Standard Polishing): Standard polishing without any additional surface treatment. PL1 (Nd:YAG Laser): Standard polishing followed by surface grinding with Nd:YAG laser. PL2 (Er:YAG Laser): Standard polishing followed by surface grinding with Er:YAG laser. PB (Diamond Bur): Standard polishing followed by surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute. PBL1 (Diamond Bur + Nd:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Nd:YAG laser irradiation. PBL2 (Diamond Bur + Er:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Er:YAG laser irradiation. MPa (megapascal); n (sample size)

Table 2: Mean and standard deviation of surface roughness (Ra) and surface profile height (Rz) for different treatment groups

Group	Measure (µm)	Mean (µm)	Standard Deviation (µm)
PB	Ra	2.20	0.51
	Rz	13.21	3.24
PBL1	Ra	1.88	0.45
	Rz	10.40	3.59
PBL2	Ra	1.44	0.45
	Rz	6.50	0.88
PL1	Ra	1.10	0.31
	Rz	5.70	1.19
PL2	Ra	0.90	0.26
	Rz	5.40	1.08
SP	Ra	0.88	0.29
	Rz	5.36	1.59

SP (Standard Polishing): Standard polishing without any additional surface treatment. PL1 (Nd:YAG Laser): Standard polishing followed by surface grinding with Nd:YAG laser. PL2 (Er:YAG Laser): Standard polishing followed by surface grinding with Er:YAG laser. PB (Diamond Bur): Standard polishing followed by surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute. PBL1 (Diamond Bur + Nd:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Nd:YAG laser irradiation. PBL2 (Diamond Bur + Er:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Er:YAG laser irradiation. Ra (average surface roughness, micrometre); Rz (mean surface profile height, micrometre); µm (micrometre)

Table 3: Pairwise Comparisons of surface profile height (Rz) between Experimental Groups (Significance Level)

Groups	SP	PL1	PL2	PB	PBL1	PBL2
SP	-	0.883	0.739	0.000	0.001	0.241
PL1	0.883	-	0.480	0.000	0.001	0.306
PL2	0.739	0.480	-	0.000	0.000	0.132
PB	0.000	0.000	0.000	-	0.330	0.001
PBL1	0.001	0.001	0.000	0.330	-	0.021
PBL2	0.241	0.306	0.132	0.001	0.021	-

SP (Standard Polishing): Standard polishing without any additional surface treatment. PL1 (Nd:YAG Laser): Standard polishing followed by surface grinding with Nd:YAG laser. PL2 (Er:YAG Laser): Standard polishing followed by surface grinding with Er:YAG laser. PB (Diamond Bur): Standard polishing followed by surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute. PBL1 (Diamond Bur + Nd:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Nd:YAG laser irradiation. PBL2 (Diamond Bur + Er:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Er:YAG laser irradiation. Rz (mean surface profile height, µm)

er roughness (p= 0.005). Also, there was a significant difference between the PL1 and the PBL2 (p= 0.005) (Table 4).

Discussion

Our findings showed laser treatment alone with Nd:YAG or Er:YAG did not lead to a significant rise of shear bond strength in comparison to the control group. However, when laser treatment was followed by bur treatment, the bond strength was enhanced, suggesting a synergistic effect between the mechanical and laser treatments. In addition, the surface roughness was higher in the bur-and-combination groups compared to the laser-only groups, indicating that the combination of the mechanical and laser surface modifications is more effective in changing the surface characteristics of zircon nia. The findings also indicated the benefit of combining the mechanical and laser treatments for enhancing both the roughness and bond strength of zirconia surfaces.

Table 4: Pairwise Comparisons of surface roughness (Ra) between Experimental Groups (Significance Level)

Groups	SP	PL1	PL2	PB	PBL1	PBL2
SP	-	0.377	0.985	0.000	0.000	0.000
PL1	0.377	-	0.387	0.000	0.005	0.005
PL2	0.985	0.387	-	0.000	0.000	0.000
PB	0.000	0.000	0.000	-	0.409	0.409
PBL1	0.000	0.005	0.000	0.409	-	1.000
PBL2	0.000	0.005	0.000	0.409	1.000	-

SP (Standard Polishing): Standard polishing without any additional surface treatment. PL1 (Nd:YAG Laser): Standard polishing followed by surface grinding with Nd:YAG laser. PL2 (Er:YAG Laser): Standard polishing followed by surface grinding with Er:YAG laser. PB (Diamond Bur): Standard polishing followed by surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute. PBL1 (Diamond Bur + Nd:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Nd:YAG laser irradiation. PBL2 (Diamond Bur + Er:YAG Laser): Surface grinding with a red and blue band diamond bur using a high-speed turbine and water irrigation for one minute, followed by Er:YAG laser irradiation. Ra (average surface roughness, µm)

In this study, we found that surface treatments affected the surface roughness of zirconia. The surface roughness values varied across different treatment groups, with diamond bur treatment resulting in the highest surface roughness, followed by Nd:YAG laser and Er:YAG laser treatments. In this regard, Strasser *et al.* [14] and Kim *et al.* [15] reported similar findings where diamond bur treatment resulted in increased surface roughness compared to other methods, including sandblasting and laser treatments. The increase in surface roughness is important because it improves mechanical interlocking between the zirconia surface and resin-based composites, and as a result it might improve bond strength.

Regarding laser treatments, our study found that Nd:YAG laser treatment resulted in a non-significant higher surface roughness compared to the Er:YAG laser treatment. This can be attributed to the specific interaction of each laser with the zirconia surface. The Nd: YAG laser works via a photothermal effect, where its energy is poorly absorbed by the zirconia, leading to localized heating, melting, and potential phase transformation from tetragonal to monoclinic zirconia [14]. In contrast, the Er:YAG laser is highly absorbed by water and hydroxyl groups in the material, causing a photoablative effect that removes layers of the surface and creates a microporous texture [15].

Akin *et al.* [16] reported that the highest shear bond strength was observed in the Er:YAG laser and silica-coated group, which contrasts with our findings where Nd:YAG and Er:YAG lasers exhibited comparable bond strengths. This discrepancy may be attributed to differences in the type of resin cement used, the composition of the zirconia, or variations in laser parameters. In the aforementioned study [16], the laser-treated groups were compared with an airborne particle abrasion group, whereas our study did not include sandblasting, which may have influenced the overall ranking of bond strengths across the groups. Furthermore, another study reported the opposite trend, with Er:YAG laser showing higher surface roughness than Nd:YAG [17]. The difference between the studies may be due to the variation in laser parameters, such as energy levels and exposure time. In our study, Nd: YAG laser was applied at 100 mJ, whereas the other study used 200 mJ [17], which might explain the discrepancy in results. These findings suggest that laser parameters play a major role in determining the surface roughness of zirconia, and adjusting them can help optimize bond strength while minimizing potential damage to the material.

With respect to bonding strength, our work showed that diamond bur treatment had the greatest shear bond strength to resin composite, followed by Nd:YAG laser treatment. Groups treated with Nd:YAG lasers were reported to have greater bond strengths compared to Er:YAG laser-treated groups, which is in accordance with the results published by Paranhos *et al.* [18] and Akin *et al.* [16]. Both Paranhos *et al.* [18] and Akin *et al.* [16] reported laser treatments, particularly Nd:YAG, had decreased bond strength compared to mechanical surface treatments including sandblasting or diamond bur usage. Furthermore, a systematic review and meta-analysis [19] on 37 *in vitro* studies concluded that laser irradiation can significantly improve the surface roughness (mean difference: 0.96; 95% confidence interval: 0.86, 1.06) and bond strength (mean difference: 3.10; 95% confidence interval: 2.60, 3.60) of yttria-stabilized tetragonal zirconia polycrystal zirconia compared to untreated controls, although the Er:YAG laser did not show a significant difference in bond strength relative to controls (mean difference: 0.22; 95% confidence interval: −0.44, 0.88) [19]. In contrast, another systematic review involving six *in vitro* studies found that while laser phototherapy improved surface roughness in glass ceramics, it did not achieve bond strengths equivalent to conventional hydrofluoric acid etching [20]. Moreover, a study by Abdullah *et al.* [21] on 120 samples documented that the shear bond strength of ultra-translucent zirconia increased significantly following Er:YAG laser treatment, while translucent and high-translucent zirconia types did not show a significant increase. The differences suggest that laser parameters such as energy levels and exposure time and type of zirconia can affect outcomes of bonding. Our findings demonstrated that the use of Nd:YAG at lower energies (100 mJ) was adequate to cause adequate surface roughening with minimal thermal damage, and integrating mechanical and laser treatments may further customize the bonding interface.

Based on our findings, diamond bur treatment may be a preferred method for improving bond strength to resin composites, but clinicians should consider to balance the roughness to avoid damaging adjacent teeth. It is also important to consider the potential long-term effects of surface roughening on the material's strength and aging. Increased surface roughness can create stress concentration points, which may reduce the flexural strength of zirconia restorations. Furthermore, the induced surface stress from mechanical or thermal treatments can promote the undesirable tetragonal-to-monoclinic phase transformation, which is the primary mechanism of low-temperature degradation or age-hardening. While this transformation can be beneficial at the crack tip by imparting toughness, an extensive surface transformation may compromise the long-term structural integrity of the restoration. This highlights the delicate balance between achieving strong immediate bond strength and maintaining the material's durability over time. Therefore, in clinical practice, it is critical to apply appropriate surface treatments before cementing zirconia restorations to ensure durable bond strength while minimizing potential material degradation.

Our study showed that the control group, which received no surface treatment, had the lowest shear bond strength. This finding supports the concept that surface treatment is necessary to improve the bond between zirconia and resin composites. Kim *et al*. [15] and Akin *et al.* [22] have shown that untreated zirconia surfaces have poor bonding strength due to their smoothness and inert surface characteristics. Surface treatments such as sandblasting, laser irradiation, and diamond bur treatment are necessary for improving the surface energy and creating micro-retentive features that facilitate better bonding. Comparatively, studies on zirconia surface modification provide further insight into these outcomes. In this regard, an *in vitro* study on 60 zirconia samples demonstrated that sandblasting resulted in significantly higher roughness than laser irradiation [23]. While increased surface roughness is desirable for micromechanical retention and resin cement bond strength, a very high surface roughness may lead to adverse clinical effects such as increased wear of opposing dentition and potential compromise of the integrity of zirconia structure [24]. Therefore, clinicians should consider combining mechanical and laser treatments for a balanced and effective approach to zirconia surface preparation.

This study had limitations that should be acknowledged. First, only one of the ceramic materials was tested, and the effects of the surface treatments on the other ceramics should be explored in future studies. Second, we only used a specific holder for the Er:YAG laser application, in the absence of any patterned scanning template that can ensure equal distribution of the light over the samples, and could affect the consistency of the results. Third, in the treatment using Nd:YAG laser, there was no temperature change for the samples, but with the application of Er:YAG laser, the samples warmed up, which can potentially affect the roughness of the surface. The heat treatment could have promoted phase transformation within the zirconia, particularly in the tetragonal form, which can affect its surface roughness and bond strength. These factors need to be addressed in future investigations to understand underlying mechanisms and control surface treatments on zirconia. Fourth, the *in vitro* nature of the study cannot completely replicate the conditions in the oral environment, such as dynamic loading, salivary conditions, and long-term exposure to thermal cycling. Future studies should assess other materials, treatment variables, and *in vivo* models to further validate and extend the clinical relevance of these findings. Although our study provides valuable data on the immediate effects of surface treatments, the absence of thermocycling or other aging protocols is a limitation and future research should investigate the long-term durability of the treated surfaces. Also, we did not include airborne particle sandblasting in our study, but due to its clinical relevance, it can be used in future research.

Conclusion

Different surface treatments significantly affected shear bond strength and surface roughness of zirconia. A combination of mechanical and laser treatments had greater bond strength and roughness compared to control and laser-only groups. Clinicians may therefore use a combination of mechanical and laser treatments to increase the adhesion of zirconia restorations, particularly in restorations where adhesive bonding is important for the longevity and success of the restoration.

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Ethical approval

The current study was approved by the Ethics Committee of Qom University of Medical Sciences, Qom, Iran (ethics codes: IR.MUQ.REC.1399.113 and IR.MUQ. REC.1398.120). All international and national guidelines were followed.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interests

The authors declare that they have no conflict of interests.

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