Original Article

Effect of Sandblasting, Silica Coating, and Erbium: Yttrium-Aluminum-Garnet Laser Treatment on the Shear Bond Strength of Self-adhesive Resin Cement to Alumina Ceramics

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Abstract

Objective: The aim of this study was to investigate the different surface treatments on the bond strength of self-adhesive resin cement to high-strength ceramic. **Materials and Methods:** Ninety aluminum oxide ceramic (Turkom-Ceramic Sdn. Bhd., Kuala Lumpur, Malaysia) specimens were produced and divided into nine groups to receive the following surface treatments: control group, no treatment (Group C), sandblasting (Group B), silica coating (Group S), erbium: yttrium-aluminum-garnet (Er:YAG) laser irradiation at 150 mJ 10 Hz (Group L1), Er:YAG laser irradiation at 300 mJ 10 Hz (Group L2), sandblasting + L1 (Group BL1), sandblasting + L2 (Group BL2), silica coating + L1 (Group SL1), and silica coating + L2 (Group SL2). After surface treatments, surface roughness (SR) values were measured and surface topography was evaluated. Resin cement was applied on the specimen surface, and shear bond strength (SBS) tests were performed. Data were statistically analyzed using one-way ANOVA and Tukey's multiple comparisons at a significance level of $P < 0.05$. **Results:** Group S, SL1, and SL2 showed significantly increased SR values compared to the control group ($P < 0.05$); therefore, no significant differences were found among the SR values of Groups B, BL1, BL2, L1, and L2 and the control group ($P > 0.05$). Group S showed the highest SBS values, whereas the control group showed the lowest SBS values. **Conclusion:** Silica coating is the most effective method for resin bonding of high strength ceramic, but Er:YAG laser application decreased the effectiveness.

Keywords: *Alumina oxide ceramic, laser, resin cement, shear bond strength, silica coating*

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Introduction

All-ceramic restorations have become very popular with both patients and clinicians because of their highly aesthetic results, biocompatibility, and chemical stability. High-strength ceramic systems such as lithium disilicate ceramics, infiltrated alumina ceramic, densely sintered aluminum oxide ceramic, and zirconium oxide are commonly used in dentistry, and the range of their clinical indications is expanding constantly.[1-6]

The cementation procedure has a crucial impact on the longevity of the restoration. Some clinical studies have reported that clinical failures may occur because of an inadequate luting performance of restorations.[1,7,8] Conventionally cemented all-ceramic restorations were reported to have poorer adhesive success rates than restorations cemented with adhesive resin cements.[7-9] Furthermore, cementation of all-ceramic restorations with resin cement can enhance the fracture resistance, retention of restoration, and marginal adaptation.[4,10] The ceramic structure directly affected the bonding

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mechanism.[11] High glass phase content ceramics have demonstrated excellent adhesion to resin cements by surface treatments such as acid etching or sandblasting; however, high alumina content ceramics have not demonstrated high bond strength values to resin cement with commonly used precementation treatments. Because high crystalline content ceramics without silica and glass phase makes them unsuitable for acid applications and silanization.[4,7] Diverse treatments have been suggested with the aim of promoting high bond strength between resin cements and high alumina content ceramic.[10-15]

Sandblasting is a procedure commonly used to clean the surface of ceramic materials and to increase microretentive structures for the bonding process.[8,9,11-14] Silica and aluminum oxide particles with sizes from 25 to 250 μm have been used on the inner surface of high strength ceramics and improve the wettability for resin penetration.[7-11,16,17] Razak *et al*.[18] reported that sandblasting improved the bond strength of resin cement to high strength ceramic Turkom-Cera. Valandro *et al*.[19] evaluated the effect of silica coating and sandblasting on bond strength between resin cement and high alumina content ceramics and reported that silica coating provided higher bond strength values than with airborne particle abrasion with Al_2O_3. Similar to the previous study, other studies were reported that silica-modified surfaces are chemically more reactive to the resin.[7-12]

Recently, researches are being carried out on laser applications to enhance the bond strength between indirect restorations and resin cements.[15,20-25] Erbium: yttrium-aluminum-garnet (Er:YAG) laser is the most frequently used laser system for surface treatment of dental materials.[21-23] This laser produces microexplosions on the materials' surface, resulting in macroscopic and microscopic irregularities.[21] A different pulse duration mode, the quantum square pulse (QSP) mode (LightWalker AT, Fotona, Ljubljana, Slovenia), has also been introduced to Er:YAG laser technology recently. The QSP pulse is consisted of five pulselets (quantas) of 50 μs pulse duration, which follow each other at an optimally fast rate. The main advantage of the QSP pulse is that it minimalizes the undesirable effects of laser beam scattering and absorption in the debris cloud during ablation, so the QSP pulse can create sharp and well-defined surface morphology.[24,25] There is no consensus in the literature about the laser parameters for optimal bond strength of the resin cement and ceramics. Kasraei *et al*.[23] evaluated the effect of Er:YAG laser on high ceramic zirconia and reported that Er:YAG laser improves the bond strength of resin cement to zirconia ceramic. Despite to this study, Foxton *et al*.[15] stated that Er:YAG laser treatment of the high strength alumina ceramic surface did not result in an improvement in bond strengths compared with the sandblasted and untreated specimens. Currently, limited information about laser applications for bonding resin cement to high strength alumina ceramics can be found in the literature.

According to the requirements of ISO 10477,[26] the accepted minimum shear bond strength (SBS) value at the interface of resin-based materials and substrate is 5 MPa. However, minimum clinical SBS value of resin-based materials under oral conditions was reported as 10–12 MPa in the literature.[27,28] In the present study, to compare the SBS values of tested specimens, both ISO and the literature values have been taken into account.

Due to the increased use of all-ceramic restorations with high alumina content, it is important to evaluate the effect of different surface treatments and their combination on bond strength values between ceramic materials and resin cements. Thus, the aim of this study was to evaluate the effect of surface treatments on the bond strength of high alumina content ceramic to self-adhesive resin cement. The null hypothesis was that the applied surface treatments would not enhance the bond strength of self-adhesive resin cement to high strength alumina ceramic.

Materials and Methods

The composition and manufacturer of the materials and equipment used in the present *in vitro* study are described in Table 1. A custom-made silicone mold with a diameter of 10 mm × 10 mm × 2 mm was prepared to produce aluminum oxide ceramic specimens (Turkom-Ceramic Sdn. Bhd., Kuala Lumpur, Malaysia). The mold was filled with alumina gel and was left for drying. After 24 h, alumina gel was taken from the mold and fired in the porcelain oven (VITA Inceramat II, VITA Zahnfabrik, Germany) (temperature increase rate, 100°C/min; holding temperature, 1150°C; and holding time, 5 min). Crystal powder was mixed with water and the sintered specimens were fired again in the same furnace for 30 min at 1180°C for crystallization. The excess crystals were removed with a laboratory micromotor (NSK Ultimate XL-K, Kanuma Tochigi, Japan). Thus, 90 specimens of sintered aluminum oxide ceramic in the dimensions of 10 mm × 10 mm × 2 mm were prepared. These specimens were embedded in an autopolymerizing acrylic resin (Meliodent, Heraeus Kulzer GmbH, Hanau, Germany), and the bonding surfaces of each specimen were polished with 600 and 800 grit silicon carbide paper under running water, respectively. Then, the specimens were cleaned in an ultrasonic cleaner (Eurosonic E4D, Euronda, Vicenza, Italy) for 10 min with distilled water

and air-dried before surface treatments. The specimens were randomly divided into nine groups (n = 10) and the same researcher applied the following surface treatments:

1. Group C (control); no treatment
2. Group B (sandblasting); specimens' surfaces were abraded with 50 μm Al_2O_3 particles (Cobra, Renfert GmbH, Hilzingen, Germany) for 15 s at a pressure of 2.7 atm and a distance of 10 mm perpendicular to the bonding surface using a dental sandblaster (Basic Classic, Renfert GmbH, Hilzingen, Germany). The specimens were then cleaned with distilled water in an ultrasonic cleaner for 60 s and dried with oil-free air
3. Group S (silica coating); specimens' surfaces were silica coated with Cojet Sand (3M ESPE, St. Paul, MN, USA) of 30 μm with Cojet System at a pressure of 2.7 atm and a distance of 10 mm perpendicular to the bonding surface according to the manufacturers' instructions. The specimens were then cleaned with distilled water in an ultrasonic cleaner for 60 s and dried with oil-free air
4. Group L1 (laser irradiation 1); Er:YAG laser (LightWalker AT, Fotona, Ljubljana, Slovenia) with a wavelength of 2940 nm was applied using a noncontact handpiece (H02-N, 0.9 mm focal spot size) to the specimens' surfaces while the laser beam was aligned perpendicular to the specimen surface at a distance of 10 mm for 15 s. The entire surface of the specimen was scanned manually with the laser beam while being cooled with water and air. The laser parameters were set as follows: 150 mJ (pulse energy), 1.5 W (power), QSP mode, 10 Hz (pulses per seconds), and 15 J/cm^2 (energy density). After laser irradiation, specimen surfaces were dried for 20 s with oil-free compressed air
5. Group L2 (laser irradiation 2); Er:YAG laser with a wavelength of 2940 nm was applied using a noncontact handpiece (H02-N, 0.9 mm focal spot size) to the specimens' surfaces while the laser beam was aligned perpendicular to the specimen surface at a distance of 10 mm for 15 s. The entire surface of the specimen was scanned manually with the laser beam while being cooled with water and air. The laser parameters were as follows: 300 mJ (pulse energy), 3 W (power), QSP mode, 10 Hz (pulses per seconds), and 30 J/cm^2 (energy density). After laser irradiation, specimen surfaces were dried for 20 s with oil-free compressed air
6. Group BL1 (sandblasting and laser irradiation 1); specimens' surfaces were abraded using the same parameters described for Group B. After sandblasting, Er:YAG laser irradiation was applied using the same parameters described for Group L1
7. Group BL2 (sandblasting and laser irradiation 2); specimens' surfaces were abraded using the same parameters described for Group B. After sandblasting, Er:YAG laser irradiation was applied using the same parameters described for Group L2
8. Group SL1 (silica coating and laser irradiation 1); specimens' surfaces were coated with silica using the same parameters described for Group S. After silica coating, Er:YAG laser irradiation was applied using the same parameters described for Group L1
9. Group SL2 (silica coating and laser irradiation 2); specimens' surfaces were coated with silica using the same parameters described for Group S. After silica coating, Er:YAG laser irradiation was applied using the same parameters described for Group L2.

For topographical surface evaluation of each test group, an additional specimen in the dimensions of 10 mm × 10 mm × 2 mm was prepared and analyzed by standard error of the mean (SEM) (JSM-6010 LA, Jeol Ltd, Tokyo, Japan) at ×1000 magnification.

A profilometer (Perthometer M2, Mahr GmbH, Göttingen, Germany) was used to measure the R_a (average roughness height) in micrometers (μm) after each surface treatment. Three measurements at different locations were recorded for each specimen (n = 10/group), and the average of these three measurements was used to obtain the R_a value of each specimen.

Cylindrical (3 mm × 3 mm) self-adhesive resin cement (Panavia SA Cement, Kuraray Dental, Tokyo, Japan) was polymerized on the center of the surface using a specially designed split mold. After cleaning the overflowing cement residues with the help of a small brush, it was polymerized with LED light (Led G, Woodpecker, Guangxi, China) for 10 s according to the manufacturers' instructions.

After keeping the specimens for 24 h in 37°C distilled water, SBS tests were conducted using a mechanical testing machine (Model 3340, Instron Corporation, USA) with a 2 kN load cell. A knife-edge shearing rod running at a crosshead speed of 1 mm/min closely to the aluminum oxide–resin cement interface was used for loading. The maximum shear load immediately before debonding was recorded. The following formula was used to calculate SBS data; fracture load/bonding surface area = N/mm^2 = MPa.

Statistical analysis was performed using statistical software (SPSS 17.0, Chicago, IL, USA). The Kolmogorov–Smirnov test was used to confirm that SBS and SR data were normally distributed. The mean values and standard deviations per group were calculated. One-way ANOVA and Tukey's *post hoc* test were used

for analyzing the interactions and differences among the groups at a significance level of $P < 0.05$.

Types of failures were recorded following the SBS tests, and the fracture surfaces were evaluated using SEM at ×100 magnification. The failure modes were classified as "adhesive failure at the resin–ceramic interface," as "cohesive failure within the luting resin cement," or as "mixed" when both failures happened together.

Results

The mean and standard deviation of surface roughness values are presented in Table 2. According to the variance analysis used for the comparison of the values that were obtained, statistically significant differences were found regarding the surface roughness values ($P < 0.05$). The highest SR value was found in Group S (2.77 ± 0.51 μm), whereas the lowest SR value was found in the control

Table 1: Summary of the materials and equipment used in this study

Material	Product name	Manufacturer	Composition	Lot number
Aluminum oxide ceramic	Turkom-Cera	Turkom-Ceramic Sdn. Bhd., Kuala Lumpur, Malaysia	Aluminum oxide (99.98%)	AB00809
Self-adhesive resin cement	Panavia SA Cement	Kuraray Dental, Tokyo, Japan	Bis-GMA*, TEGDMA*, HEMA*, 10-MDP*, silanated barium glass filler, silanated colloidal silica	920062
Aluminum oxide sand	Cobra	Renfert GmbH, Hilzingen, Germany	Aluminum oxide sand of 50 μm mean particle size	15941205
Tribochemical silica coating	The Cojet system	3M ESPE, St. Paul, MN, USA	Silicatized sand of 30 μm mean particle size	625642
Dental laser	LightWalker AT	Fotona, Ljubljana, Slovenia	Er:YAG* laser with a wavelength of 2.940 nm	
Dental sandblaster	Basic classic	Renfert GmbH, Hilzingen, Germany	Blasting with special mixing chamber technology by using abrasive from 25-70 μm	
Polymerizing unit	Led G	Woodpecker, Guangxi, China	Blue LED* light, wavelength: 420-480 nm, light intensity: 1000-1200 mW/cm^2	

*Bis-GMA=Bisphenol A-glycidyl methacrylate; TEGDMA=Triethylene glycol dimethacrylate; HEMA=Hydroxyethylmethacrylate; 10-MDP=10-methacryloyloxi-decyl-dihydrogen-phosphate; LED=Light-emitting diode; Er:YAG=Erbium: yttrium-aluminum-garnet

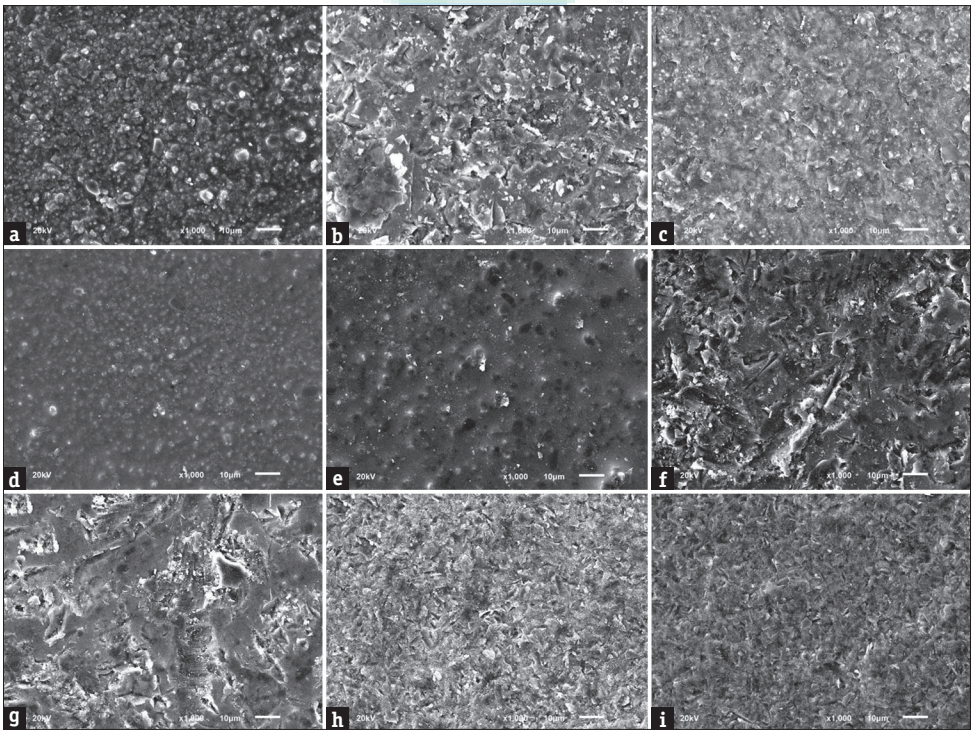

Figure 1: Scanning electron microscopy image of test groups. (a) Control group, (b) Group B, (c) Group S, (d) Group L1, (e) Group L2, (f) Group BL1, (g) Group BL2, (h) Group SL1, (i) Group SL2

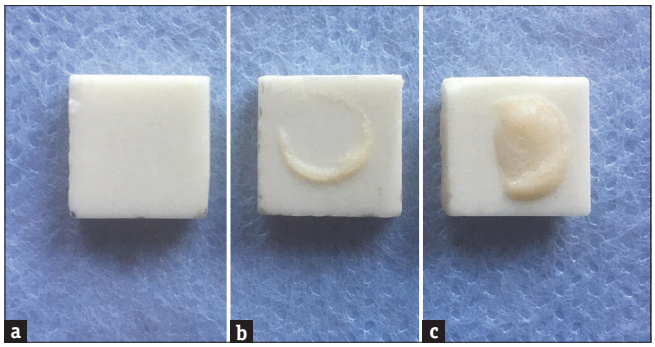

Figure 2: The images of failure types; (a) adhesive, (b) mix, (c) cohesive

Table 2: Mean and standard deviation of surface roughness values of test groups

Group	Mean±SD*
C[a]	0.82±0.31
B[a]	1.20±0.28
S[b]	2.77±0.51
L1[a]	0.95±0.47
L2[a]	1.16±0.28
BL1[a]	0.99±0.26
BL2[a]	0.83±0.26
SL1[c]	1.50±0.47
SL2[d]	2.08±0.34

*Values are given in μm. Different superscript letters indicate statistically significant differences between groups (P<0.05). SD=Standard deviation

Table 3: Mean and standard deviation of shear bond strength values of test groups

Group	Mean±SD*
C[a]	6.63±0.75
B[d]	27.90±4.41
S[e]	39.36±5.60
L1[b]	13.94±3.75
L2[b,c]	21.22±2.32
BL1[b,c]	20.18±4.14
BL2[b,c]	17.00±4.86
SL1[d]	24.88±3.26
SL2[d]	27.09±4.28

*Values are given in MPa. Different superscript letters indicate statistically significant differences between groups (P<0.05). SD=Standard deviation

group (0.82 ± 0.31 μm). Group SL1 (1.50 ± 0.47 μm) and Group SL2 (2.08 ± 0.34 μm) demonstrated statistically significant higher SR values than the other groups, except Group S (P < 0.05), and statistically significant differences were found between them. On the other hand, no significant differences were found among the Groups B (1.20 ± 0.28 μm), BL1 (0.99 ± 0.26 μm), BL2 (0.83 ± 0.26 μm), L1 (0.95 ± 0.47 μm), L2 (1.16 ± 0.28 μm), and the control group (0.82 ± 0.31 μm) (P > 0.05).

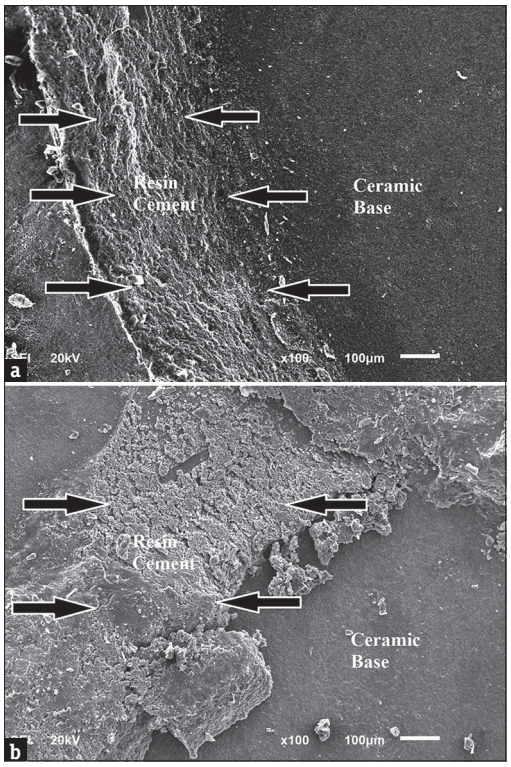

Figure 3:(a) Scanning electron microscopy image of Group S (silica coating) after debonding; mix fracture, (b) SEM image of Group SL1 (silica coating+laser 1) after debonding; mix fracture

SEM images of surface treatments are shown in Figure 1. Group B [Figure 1b] and Group S [Figure 1c] demonstrated irregularities on the surface, but the irregularities, which were found on the surface of Group S, were more homogenous and uniform than Group B. Numerous surface defects but no surface cracks were detected for Groups L1 and L2 [Figure 1d and e]. After laser irradiation, the irregularities on the surfaces of Groups B and S became more uniform [Figure 1f-i].

The mean and standard deviation of SBS values are presented in Table 3. According to the variance analysis used for the comparison of the values that were obtained, statistically significant differences were found regarding the surface treatments (P < 0.05). Group S (39.36 ± 5.60 MPa) displayed the highest SBS values, whereas the lowest SBS values were displayed in the control group (6.63 ± 0.75 MPa). Group L2 demonstrated statistically significant higher SBS values than Group L1 (P < 0.05). Group B showed statistically significant higher SBS values than Groups BL1 and BL2 (P < 0.05). Group S showed statistically significant higher SBS values than Groups SL1 and SL2 (P < 0.05). All SBS values were found higher than 5 MPa, so all tested specimens met the standard of ISO 10477.[26] However, SBS values of Group C were under 10–12 MPa which is critical for clinical service in the oral cavity.[27,28]

Table 4: Failure modes of the test groups

Surface treatment	Failure modes			Total
	Adhesive	Cohesive	Mix	
Control	10	0	0	10
Sandblasting	8	0	2	10
Silica coating	4	2	4	10
Laser 1	9	0	1	10
Laser 2	9	0	1	10
Sandblasting + laser 1	6	0	4	10
Sandblasting + laser 2	7	0	3	10
Silica coating + laser 1	4	0	6	10
Silica coating + laser 2	5	1	4	10
Total	62	3	25	90

All failure types of debonding were observed in the present study [Figure 2]. The majority of the specimens in the test groups showed adhesive and mix fractures at the ceramic–cement interface with small amounts of cement remnants on the ceramic surface [Table 4]. Only two specimens in Groups S and one specimen in Group SL1 showed cohesive failure. Groups S and SL1 exhibited greater amounts of cement-retained on the surface than the other groups. The results of this study indicated that the mode of bond failure was primarily adhesive and mix between the cement and high strength oxide ceramic material. SEM evaluations of fractures after SBS tests are shown in Figure 3.

Discussion

This study evaluated the effect of different surface treatments on the bond strength of self-adhesive resin cement to high strength alumina ceramic. The results of this study demonstrated that all surface treatments improved the bond strength of self-adhesive resin cement to high strength alumina ceramic. Therefore, the null hypothesis that the applied surface treatments would not enhance the bond strength of self-adhesive resin cement to high strength ceramic was rejected.

Micromechanical and chemical bonding are the basic points of a strong resin bond to ceramic surface. Adequate surface properties are commonly obtained by grinding, abrasion with diamond rotary instruments, airborne particle abrasion with aluminum oxide or silica, acid etching, laser irradiation, and combinations of any of these methods.[7-9,12-15] Type of ceramic is important to choose the effective surface treatment because ceramic microstructure has a significant effect on the bond strength of resin and ceramic.[7] Conventionally, silica-based ceramics' micromechanical and chemical bonding mechanism is constituted by etching with hydrofluoric acid and silanization.[29] Since aluminum oxide ceramics contain very little or even no silica, acid etching, and silane would not react with these ceramics as much as silica-based ceramics. For this reason, in the present study, acid etching and silanization were not used for aluminum oxide ceramic surface treatment.

Various resin cement systems have been suggested for optimum and durable bonding of high strength ceramics.[29,30] The monomer 10-methacryloyloxydecyl dihydrogen phosphate (MDP) was originally designed to bond to metal oxides and its use has been extended to oxide ceramics.[31] Studies suggested that chemical bonding might be constituted between aluminum oxide or zirconium oxide ceramic and MDP.[30-34] Hence, in the present study, self-adhesive resin cement, which contains MDP and is known with its high degree of adhesion, was used for bonding evaluations.

Airborne particle abrasion with Al_2O_3, an effective and practical method, increased the surface area and improved the wettability of the high strength oxide ceramic.[8,10,34] Kern[12] and Hummel and Kern[10] reported that instead of using chemical bonding methods, sandblasting is crucial for cleaning and activating the high strength oxide ceramics. Bagheri *et al*.[35] reported that sandblasting with Al_2O_3 significantly increased the bond strength of the high strength zirconia ceramic. In agreement with the previous studies,[8,10,34,35] in the present study, sandblasting group (27.90 ± 4.41 MPa) showed statistically significant higher SBS values than control group ($P < 0.05$). According to the surface roughness analyses, sandblasted specimens demonstrated increased surface roughness values compared to the control group [Figure 1b].

Tribochemical silica coating is an alternative method to improve the bond strength between resin and ceramic. Passos *et al*.[14] compared the bond durability between sandblasting with Al_2O_3 and silica coating for In-Ceram alumina ceramics. They reported similar bond durability with either 50 μm alumina or 30 μm silica particles. However, in the present study, silica-coated group presented a statistically significant higher SBS values than sandblasting group ($P < 0.05$). Similar to the present study, Kılıc *et al*.[36] have concluded that sandblasting with 50 μm Al_2O_3 or silica coating had a positive effect on SBS between alumina ceramic and resin cement. These differences can be associated with the structure of high strength alumina ceramics that used in these studies. In-Ceram alumina ceramics contains Al_2O_3 at 82%; however, Turkom-Cera contains Al_2O_3 at 99.8%.[13] Another study evaluated the bond strength of zirconia ceramic after different surface treatments, and they reported that silica coating was an effective method to achieve an acceptable bond between zirconia ceramic and resin cement, which is in agreement with the present study.[37] Concurrently, surface roughness evaluations

supported the effect of silica coating on bond strength of self-adhesive resin cement to alumina ceramic. More surface irregularities and micro retentive grooves on silica-coated surface can be the reason of higher bond strength values [Figure 1c]. Furthermore, silica-coated surface can easily react with the methacrylate monomers of resin cement and this chemical mechanism enhances the SBS values.[38-40]

Er:YAG lasers have been previously used to etch the different types of ceramic materials surface to enhance the bond strength between ceramic and resin cement.[37] The expectation of laser irradiation on silica-based ceramic is to create a rough surface by removing the glass phase of the material.[41] There are several studies evaluating the effect of Er:YAG laser on SBS between silica-based ceramic and resin cement in the literature.[42,43] However, the number of the studies about Er:YAG laser effects on resin bonding to high strength ceramic is limited. Foxton *et al*.[15] investigated the effect of Er:YAG laser and air abrasion on alumina ceramic and they stated that bond strength of resin cement was not improved by Er:YAG laser irradiation compared to no surface treatments. In addition, other studies stated similar results to the previous study about the effect of Er:YAG laser on bond strength of resin cement to ceramic.[43,44] In contrast, Akın *et al*.[21] and Kasraei *et al*.[23] reported that Er:YAG laser treatment increased the bond strength of zirconia ceramic compared to sandblasting. Different laser parameters that used in these studies can be the reason of the varied results. Currently, there is no consensus about the accurate laser parameter for ceramic surface treatments. In the present study, laser parameters were selected as a result of the previous studies,[15,40,44] and laser irradiation of various pulse energy increased the bond strength of self-adhesive resin cement to aluminum oxide ceramic. However, when Er:YAG laser irradiation was applied after silica coating and sandblasting, a significant decrease was found compared to these groups. Because after Er:YAG laser application, the surface of silica-coated and sandblasted groups became smoother than before as shown in SEM views [Figure 1d-i].

In the present study, all tested specimens were found to be within the range of ISO 10477,[26] but clinical requirements for SBS values cannot be reached in the control. Thus, the results of this study demonstrated that high strength oxide ceramic should be pretreated before cementation for improved bonding.

The present study has some limitations; bond strength of resin cement to alumina ceramic needs to be evaluated for prolonged periods by using thermal cycling. In addition, only self-adhesive resin cement was used without simulating the oral cavity conditions, which would have some influence on bonding effectiveness. Different laser parameters for resin bonding to aluminum oxide ceramics must be further investigated.

Conclusion

According to the results of this *in vitro* study, it can be concluded that all tested surface treatments increased the bond strength of self-adhesive resin cement to alumina ceramic. Silica coating is the most effective method for resin bonding to alumina ceramic, but using this method with Er:YAG laser decreased the bond strength. At the same time, Er:YAG laser application decreased the effectiveness of sandblasting for resin bonding. All SBS values of tested specimens met the standards of ISO 10477,[26] but it can be concluded that additional surface treatments should be made for optimum adhesion between resin cement and alumina ceramic.

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Conflicts of interest

There are no conflicts of interest.

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