Original Article

Shear Bond Strength of Metal brackets to Zirconia Treated with Er:YAG Laser Sandblasting and Silane

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Abstract

Background and Aim: Application of zirconia ceramics has increased. Since the commonly used surface treatment for porcelain, i.e. acid etching is not efficient for zirconia surfaces, evaluation of other surface treatment methods for zirconia is important. The aim of this study was to compare the shear bond strength (SBS) of metal brackets to zirconia treated with different powers of Er:YAG laser, sandblasting and silane.

Materials and Methods: In this experimental study, five blocks of 3 mol% yttria stabilized tetragonal zirconia ceramics (3Y-TZP-A) were cut into small cubes. After the sintering process, 72 samples were assigned to six groups (n=12). The first group did not receive any surface treatment. The second, third and fourth groups were irradiated with Er:YAG laser with 1.5 W (150 mJ), 2.5 W (250 mJ) and 3 W (300 mJ) powers, respectively in a long pulse mode for 20 seconds. The samples in the fifth group were sandblasted. The sixth group samples were silanized. After bonding of brackets to the samples, they were stored in distilled water, thermocycled and their SBS was measured by a universal testing machine. Mode of failure was assessed by a stereomicroscope.

Results: The SBS of brackets to zirconia in groups one to six was 0.31±0.23, 0.51±0.14, 1.11 ±0.40, 3.32±1.52, 9.5±2.99 and 3.88±2.20 MPa, respectively. ANOVA revealed a significant difference among the six groups. Tamhane's test showed that the SBS in group five was significantly higher than that in the other groups. Bond failure occurred at the adhesive/zirconia interface in all groups.

Conclusion: Surface treatment of zirconia with sandblasting provided appropriate bond strength of brackets for clinical applications. But, Er:YAG laser and silane did not create sufficient SBS to zirconia surfaces.

Key Words: Lasers, Shear Strength, Orthodontic Brackets, Zirconium

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Introduction

Fixed orthodontic treatment requires appropriate and acceptable bonding of brackets to the teeth. Considering the increase in number of adults with multiple tooth restorations seeking orthodontic treatment [1], research on the bond to various dental restorations seems necessary. Many studies have assessed different methods of surface treatment to improve the bond strength to amalgam and porcelain [2-4]. Recently, zirconia has gained increasing popularity as a dental ceramic due to its desirable mechanical and esthetic properties [5].

Zirconia has excellent biocompatibility [6]; its color resembles natural tooth color and its mechanical properties are similar to those of stainless steel. It has a tensile strength of 900-1200 MPa and compressive strength of 2000 MPa [7]. This material can be seen in three temperature-dependent patterns namely monoclinic, tetragonal and cubic. The tetragonal pattern is the most commonly used form of zirconia in dentistry, which is obtained by heating the zirconia to 1170°. For optimal stability at room temperature, metal oxides such as MgO, CaO and Y2O3 are added to zirconia. At present, yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is the best known and most widely used formulation of zirconia in dentistry [6, 8]. Application of acid etching technique for surface treatment of ceramics like porcelain results in adequate bond strength to metal brackets [9, 10] but this method is not efficient for use on 3Y-TZP zirconia because it has no glass or silica phase [11, 12]. Thus, finding new ways to improve the bond strength to zirconia is important.

Lasers are used in dentistry for different purposes, and application of laser for surface treatment prior to bonding of brackets has shown acceptable results. Er:YAG, Nd:YAG, Er,Cr: YSGG and CO2 lasers have been used for this purpose [13, 14]. It has been shown that irradiation of Nd:YAG laser on the surface of zirconia leads to crack formation and reduces its mechanical strength [15]. Some studies showed that irradiation of Er:YAG laser on porcelain did not increase the bond strength [16] while some others emphasized on the positive efficacy of Er:YAG laser for preparing the porcelain and zirconia surfaces [2, 17-19]. To date, only a few studies have assessed the efficacy of Er:YAG laser for improving the bond strength of metal brackets to zirconia surfaces [19].

Sandblasting and primer application are the other commonly used methods for surface treatment of ceramic surfaces. Sandblasting of ceramic surfaces eliminates impurities, increases the available bonding area and improves the wettability of luting materials [20]. It has been shown that air abrasion and metal primers significantly improve the bond strength of 3Y-TZP zirconia to dentin [21].

Therefore, the aim of this study was to determine the effect of Er:YAG laser on the shear bond strength (SBS) of metal brackets to zirconia in comparison with more common surface treatment techniques such as sandblasting and application of primer.

Materials and Methods

In this in vitro experimental study, 72 ceramic samples with 10mm×10mm×7mm dimensions were cut out of five pre-sintered blocks of 3Y-TZP-A ceramic material (Dental Direct, Spenge, Germany) using a cutting machine (Mecatome T201A; Presi, Grenoble, France), under water cooling. They were then sintered to a final dimension of 7mm×7mm×5mm in accordance with the manufacturer's instructions. The ceramic surfaces were then polished in a polishing machine using a series of silicon carbide abrasive papers in sequence (120, 220, 600, and 1,200 grit; Struers, Ballerup, Denmark) for 15 seconds under water irrigation at 150 rpm to obtain flat surfaces. The samples were then randomly divided into six groups.

Group 1 (control): No surface conditioning was done in this group.

Groups 2, 3 and 4 (laser treatment): In the second, third and fourth groups, the surfaces of zirconia samples were irradiated with Er:YAG laser (Smart 2940D Plus; DEKA laser, Florence, Italy) in long pulse mode, at a wavelength of 2940 nm and frequency of 10 Hz for 20 seconds. Output power and energy of laser in the three groups were 1.5 W and 150 mJ, 2.5 W and 250 mJ, and 3 W and 300 mJ, respectively. Irradiation was done by a sweeping motion in a noncontact mode, at approximately 2 mm distance from the surface. All samples were irradiated under water and air spray.

Group 5 (sandblasting): The zirconia surfaces were sandblasted with 50 μm Al_2O_3 particles from 10 mm distance at a pressure of 20 Psi for five seconds.

Group 6 (silane): Using a micro-brush, silane (Bisco, Schaumburg, USA) was applied on the surface of samples; the samples were given one minute to dry.

The light-cure adhesive primer (3M Unitek, Monrovia, CA, USA) was applied on all the prepared samples except for the silane group and light-cured for 10 seconds. Then, standard edgewise brackets (American Orthodontics, Sheboygan, WI, USA) of maxillary right incisors were bonded using light-cure adhesive resin (Transbond XT; 3M Unitek, Monrovia, CA, USA) and cured for 40 seconds by a LED light curing unit (Starlight Pro; Mectron Dental, Carasco, Italy) (Figure 1). After 24 hours of storage in distilled water at 37°C and thermocycling for 500 cycles between 5 and 55°C with a dwell time of 30 seconds (Vafaei Industrial, Tehran, Iran), the samples were mounted in molds using cold-cure acrylic resin. Debonding process was performed and the SBS was measured by a universal testing machine (Zwick GmbH, Ulm, Germany) with a crosshead speed of 0.5 mm/minute (Figure 2). Following debonding, the surface of each sample was examined under a stereomicroscope at ×10 magnification and the amount of adhesive remnant was recorded according to the adhesive remnant index (ARI). This index uses the following scoring system:

0. No adhesive resin remained on the zirconia surface
1. Less than 50% of adhesive resin remained on the zirconia surface
2. More than 50% of adhesive resin remained on the zirconia surface
3. All the adhesive resin remained on the zirconia surface

The data were statistically analyzed using SPSS version 20 (SPSS Inc., IL, USA). One-way ANOVA was applied to compare the six groups. Considering the heterogeneity of variances (Levene's test, $P<0.001$), pairwise comparisons were made using Post-hoc Tamhane's test. Level of significance for all statistical tests was set at $P\leq0.05$.

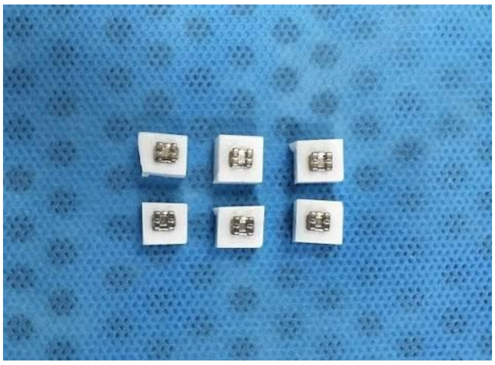

Figure 1. Bracket bonded to zirconia samples

Figure 2. Sample in universal testing machine for SBS test

Results

Descriptive statistics of SBS (MPa) in the six groups are presented in Diagram 1 and Table 1. The mean SBS of metal brackets to zirconia in groups one to six was 0.31±0.23, 0.51±0.14, 1.11 ±0.40, 3.32±1.52, 9.5±2.99 and 3.88±2.20 Mpa, respectively. ANOVA revealed a significant difference among the six groups. Post hoc Tamhane's test showed that the SBS in group 5 (sandblasted) was significantly higher than that in the other groups. Groups 1 (control) and 2 (1.5 W), and also groups 4 (3 W) and 6 (silane) had significant differences with the other groups ($P<0.05$), but the differences between themselves were not significant ($P>0.05$). The SBS in group 3 (2.5 W) had a significant difference with that in the other groups ($P<0.05$; Table 1).

Stereomicroscopic observations revealed that bond failure in all samples of the six groups occurred at the adhesive/zirconia interface.

Discussion

In this study, different powers of Er:YAG laser, sandblasting and silane were used for surface treatment of zirconia, and the SBS of metal brackets to prepared surfaces and mode of debonding in different groups were compared. The

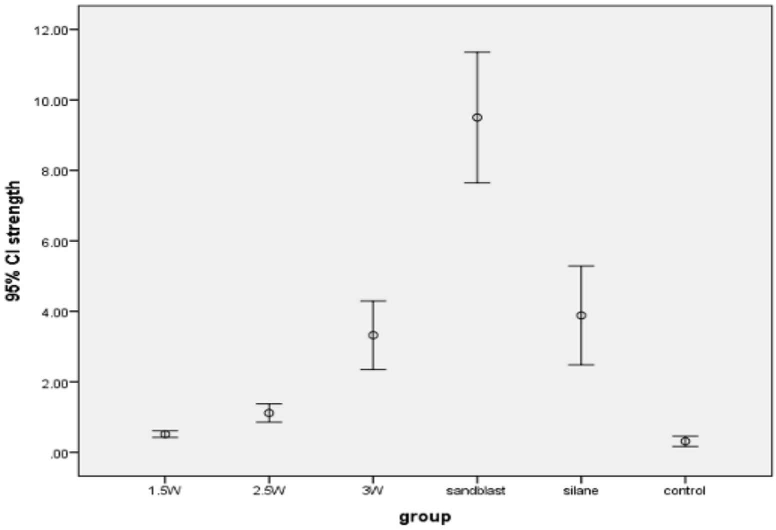

Diagram 1. The 95% confidence interval measurements and mean value of shear bond strength in the six groups (MPa)

Table 1. The mean shear bond strength of brackets to zirconia in MPa (n=12)

Group	Minimum	Maximum	Mean	Standard deviation	Pairwise comparison*
Control	0.03	0.67	0.31	0.23	a
1.5W	0.14	0.75	0.51	0.14	a
2.5W	0.41	1.74	1.11	0.40	b
3W	1.12	5.74	3.32	1.52	c
Sandblasting	4.44	15.77	9.50	2.92	d
Silane	0.73	8.90	3.88	2.20	c

***Post-hoc Tamhane's comparison test; the groups marked with different letters show significant differences at P<0.05; whereas those with the same letters are statistically comparable (P>0.05).**

results of this study revealed that the highest SBS was noted in sandblasted samples followed by silane group, 3 W laser, 2.5 W laser, 1.5 W laser and the control group, respectively. According to previous studies, 6-10 MPa range is the minimum acceptable SBS for clinical conditions [9, 22, 23]. Except for the sandblasted group, SBS of all study groups was less than the acceptable range for orthodontic treatment in the clinical setting. Bond strength of sandblasted group (9.5 MPa) had significant difference with that of other groups; also this value was greater than the results of a similar study by Yassaei et al, [19] (7.8 MPa). This difference could be due to differences in the sand-blasting methods. Similar studies on porcelain have shown that sandblasting technique besides silane application, increases the SBS and tensile bond strength (15.8 MPa and 11.6 MPa, respectively), but application of sandblasting alone yielded small shear and tensile bond strength values (2.8 MPa and 2.5 MPa, respectively) [9, 24]. In accord with our results, Akyil et al. [25] found surface treatment of zirconia with air abrasion to be more effective than CO_2, Er:YAG and Nd:YAG lasers; although we did not assess CO2 and Nd:YAG lasers in the present study. Sandblasting process creates surface roughness and micromechanical retentive grooves and improves the bond strength as such [24, 26, 27]. This is probably the reason for the higher bond strength of this group than the other groups in our study. Increase in the time of sandblasting and size of Al_2O_3 particles increases the surface roughness and further damages the surface [28]. In our study, the size of particles and duration of sandblasting were 50 µm and five seconds, respectively, which compared to similar studies, is very conservative but the results were significant; thus, these sandblasting parameters could be advised for clinical application.

Silane is a silicone-based primer or coupling agent that creates a chemical bond between two different substrates (a mineral and an organic substrate) [29]. Yassaei et al. [19] used silane along with Er:YAG laser on zirconia surfaces and obtained favorable results but Kitayama et al. [30] studied the effect of different primers on bonding of resin cements to zirconia ceramic and showed that primers containing silane coupling agent did not improve the bond strength as much as the primers containing phosphoric acid monomer or a phosphate ester monomer. Considering the above-mentioned conflicting results and the wetting effect of silane primers, in this study, we designed a silane group to assess its effect on bond strength to zirconia.

In the silane group, the SBS was 3.8 2.2 MPa while this value was 5.8 MPa in the study by Yassaei et al [19]. They used hydrofluoric acid to prepare the surface before silane application; but due to the fact that zirconia cannot be etched, application of acid etching is not the cause of this difference. Types of adhesive and silane in our study were different from those in the study by Yassaei et al [19]; it can be one of the reasons for different findings of the two studies. The SBS of our silane group showed a significant difference with that of the control group, which means that silane can improve the bond strength to zirconia. Although the applied silane in this study did not contain phosphate monomer, the wetting effect of primer was probably responsible for this improvement, as Kitayama et al, [30] also showed that conditioning the surfaces of the zirconia ceramic with any kind of primer significantly improved the tensile bond strength compared to the control group.

In the laser irradiated groups, increasing the laser power increased the bond strength. The SBS was very low in 1.5 W laser group (0.51 MPa) and had no significant difference with the control group (0.31 MPa). Bond strength of 2.5 W laser group (1.1 MPa) had a significant difference with that of other groups and the SBS of 3 W laser group (3.32 MPa) was very close to that of silane group (3.88 MPa). Yassaei et al. [19] showed that 1-2 W laser irradiation provided about 6 MPa SBS to metal brackets, but our study showed that increasing the laser power to 3 W led to less than 4 MPa SBS. In the mentioned study, duration of laser irradiation was more than ours (60 seconds versus 20 seconds); and also, silane was used in all samples. Bond strength achieved in another study following application of Er:YAG laser on porcelain was more similar to our results. Poosti et al. [16] reported the bond strength of metal brackets to porcelain after 2-3 W laser irradiation for 10 seconds to be between 2 to 4 MPa; similar to our study, they did not use silane. Akyil et al, [25] also found that Er:YAG laser irradiation with 2 W power, 200 mJ/pulse energy and 10 Hz frequency for 10 seconds increased the SBS (19.69 MPa) compared to the control group (17.02 MPa), which was not significant similar to the results of the current study. Akin et al. [17] evaluated the SBS of resin cement to zirconia ceramics after surface treatment by sandblasting and different lasers. They concluded that Nd:YAG laser and Er:YAG laser increased the SBS of zirconia compared to sandblasting and CO_2 laser treatment. The laser irradiation parameters in the Er:YAG laser group in the mentioned study was similar to our second group (1.5 W, 150 mJ, 20 seconds); their results showed higher SBS than ours (4.27 MPa versus 0.51 MPa), which may be due to the fact that the samples were not aged by thermocycling in their study. Thermocycling is necessary to simulate the thermal stresses applied to teeth in the oral environment and is advocated to decrease the SBS depending on the characteristics of the applied luting cement [31]. The differences between the value of SBS in the present study and previous investigations could be attributed to different Er:YAG laser parameters, durations of application and thermocycling process.

According to the findings of this study, the bond strength increased with an increase in laser power but there is a limit for increasing laser power on zirconia. A study concluded that high-power laser irradiation caused undesirable morphological changes in zirconia and they recommended using 200 mJ or less powers [32]. Thus, increasing the laser power to improve bond strength is not advised. Considering the low SBS obtained in laser groups of this study and the impossibility of increasing laser power to improve the bond strength, the Er:YAG laser seems not to be suitable for surface treatment of zirconia ceramics; although more studies should be conducted to assess the effect of the other laser parameters including pulse mode, pulse energy and period of laser irradiation on SBS to zirconia ceramics.

Ahrari et al. [33] assessed the effect of fractional CO_2 laser on SBS of resin cement to zirconia and compared it with air abrasion and a universal primer. They concluded that fractional CO_2 laser can significantly improve the bond strength (almost three times the control group); also, they found air abrasion to be the least effective method although the SBS was nearly two times the value in the control group. We did not use CO_2 laser in our study but we found air abrasion to be the most effective method and more efficient than Er:YAG laser. Sandblasting procedure was done differently in the two studies (2.5 bar, 15 seconds versus 20 Psi, 5 seconds); moreover, Ahrari et al. [33] used a luting cement containing 10-methacryloxydecyl dihydrogen phosphate (MDP), which is advocated to produce a chemical bond [34]. This additional chemical bond had a positive effect on the bond strength of all samples. Also, this study concluded that application of MDP containing primer can significantly increase the SBS compared to that of control and air abraded samples; we also found higher SBS in silane group samples compared to the control group but it was not significant. This is probably because our applied silane was not a MDP-based primer to form a chemical bond, and the small increase in SBS was probably due to the wetting effect of the primer. It should be noted that the samples in the study by Ahrari et al. [33] were not aged by the thermocycling process, which can cause great differences in the results. Kasraei et al, [35] also assessed the effect of CO_2 laser as a surface treatment for zirconia; they concluded that this method significantly increased the SBS of resin cement.

Evaluation of the mode of failure of samples revealed that failure occurred at the zirconia/adhesive interface without any adhesive remnant on the zirconia surface. This type of failure may be related to the low SBS achieved in the study groups. Lee et al. [36] showed different types of adhesive and cohesive failure modes; however, they used a different method and their study groups were not comparable with ours (zirconia primer, silane, sandblasting and acid etching were used). Adhesive bond failure has been reported to be more desirable in the clinical setting, because this mode of failure requires less surface cleaning and the risk of surface damage decreases [37, 38].

Considering the desirable bond strength of sandblasted group, we suggest sandblasting technique for surface treatment of zirconia surfaces. Considering the insufficient SBS of laser and silane groups, we do not recommend application of these methods but since we did not assess the possible synergistic effects of these methods, further studies are needed in this respect. Particular zirconia primers containing MDP and more efficient laser treatments like CO_2 laser are recommended to be assessed for zirconia surface treatment before bonding of metal brackets.

Conclusion

The results of this study showed that sandblasting of zirconia surfaces created sufficient SBS of brackets for clinical applications. Also, irradiation of Er:YAG laser and application of silane increased the SBS of metal brackets to zirconia surfaces, but the created bond strength was not high enough for clinical applications.

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