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Effect of Different Surface Treatments and Pressure Conditions on Shear Bond Strength of Zirconia Ceramic to Composite Resin

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A B S T R A C T

Objectives: The aim of this study was to assess the shear bond strength (SBS) of zirconia ceramic to composite resin with various surface treatments following pressure changes.

Materials and Methods: Totally, 135 zirconia blocks were prepared by computer-aided design/computer-aided manufacturing technology. The samples were divided into 9 groups (n=15). Three surface treatments including sandblasting, tribo-chemical preparation, and laser application were used. For each method, 45 samples were considered and tested under different pressure conditions. Z-Prime Plus primer was used for bonding of all samples to composite cylinders. All specimens were stored in water for 24 h, underwent thermocycling, and were then placed in a pressure chamber under normal-, high-, and low-pressure conditions. Then, the SBS test was performed for each sample. Data were analyzed by two-way and one-way ANOVA ($\alpha=0.05$).

Results: The SBS was significantly higher in sandblasting and tribochemical preparation compared with laser irradiation ($P<0.05$). There was no statistically significant difference in SBS of sandblasting and tribochemical preparation methods ($P>0.05$). Sandblasting, tribochemical preparation, and laser methods did not show a significant difference in SBS at different pressures ($P>0.05$).

Conclusion: Sandblasting and tribochemical preparation yielded a higher SBS than laser. Different pressures had no effect on SBS, irrespective of surface preparation method.

Keywords: Air Abrasion, Dental; Lasers, Solid-State; Shear Strength; Zirconium Oxide

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INTRODUCTION

Today, demand for dental ceramics, especially in the anterior region, has increased [1]. Zirconia-based ceramic crowns are widely used in dentistry because of their excellent esthetics, biocompatibility, chemical durability, and high strength [2-5]. Thus, zirconia ceramics are widely used for the fabrication of crowns in comparison with other ceramic types such as feldspathic ceramics [6-9]. Zirconia is used in orthodontic brackets, endodontic posts, implant abutments, and fixed partial dentures [1,10,11]. Due to the advances in the applications of zirconia and its non-reactivity, it is now one of the attractive areas of dental research [12,13]. There are several types of zirconia, but only three of them are used in dentistry, the most common type of which is yttria-stabilized zirconia [10,14]. The commonly used bonding techniques for other types of ceramics have not been successful for zirconia [15]. Thus, many attempts have been made to improve the zirconia ceramic bonding, and resin bond strength to zirconia. In general, two objectives can be pursued to improve the resin-zirconia bond strength: the first one is to improve the mechanical bonding techniques, and the second one is to use monomers that can chemically bond to the zirconia surface. Various methods can be used to roughen the zirconia surface and enhance the mechanical bonding to zirconia such as surface roughening by milling, sandblasting, and tribochemical preparation, as well as using different types of lasers [16]. Surface grinding is a method commonly used to roughen the surface and improve the mechanical bonding. There are many methods for grinding, which include using abrasive papers or discs, sandblasting with alumina (Al_2O_3) particles or modified particles with a size of 50-250µm, and grinding [16].

The use of tribochemical silica coating is a common technique for coating of metal alloy surfaces and dental ceramics by silica [17]. In the tribochemical technique, the ceramic surface is sandblasted by silica-coated alumina particles. These particles cover the surface with silica. This process not only prepares the surface of the material for the application of silane, but also provides a suitable micromechanical attachment [17,18].

Application of high-power lasers is one of the recent techniques to create surface porosities in ceramics and prepare them for bonding. Today, laser applications in dentistry are increasing, and they can be applied for surface treatment of the new generation of ceramic surfaces such as zirconia [19,20]. Er:YAG lasers are commonly used more than other types of lasers for preparation of restoration surfaces, as well as enamel and dentin [21,22]. Primers that contain the MDP monomer are used to provide a chemical bond to zirconia. The MDP monomer is capable of increasing the bond strength by creating a chemical bond. It has been revealed that mechanical surface treatment alone is not sufficient, and it is necessary to combine a mechanical surface treatment with application of primers containing MDP monomer to obtain a high bond strength to zirconia surfaces. Another unique feature of zirconia is that it can be transformed into a crystalline structure under different conditions; if this process is not controlled, zirconia restoration failure and loss of superficial bonding may occur [23-25]. Also, the atmospheric pressure variations can further decrease the bond strength [26]. Therefore, the purpose of this study was to assess the shear bond strength (SBS) of zirconia ceramic to composite resin, using various conditioning techniques, followed by pressure changes.

MATERIALS AND METHODS

In this in vitro experimental study, 135 zirconia discs (DD Cube X2; Dental Direkt Materials, Germany) were fabricated with 8 mm diameter and 5mm thickness. The zirconia blocks were prepared based on the manufacturer's instructions using a computer-aided design/computer-aided manufacturing system (Versamill 5×200; Axsys Dental Solutions, Wixom, USA), and then sintering was performed. Subsequently, all specimens were mounted in self-cure acrylic resin (Meliodent, Heraeus Kalzer Dental Ltd., Hanau, Germany). The blade of the cutting machine for all samples was completely parallel to the bonded surface at the interface of the cylinder and ceramic.

Surface treatments:

The samples were randomly divided into three equal groups for the three surface treatments. For sandblasting of ceramic surfaces, 50-µm aluminum oxide particles (Danvile Materials, San Roman, USA) were used. Sandblasting was performed in a direction perpendicular to the disc surface at a distance of 10mm and at 2 bar pressure for 10s. It is noteworthy that the same conditions were considered for tribochemical silica coating technique, but the silica-coated particles (Cojet SandTM Sand; 3M ESPE, St. Paul, MN, USA) were used. The Er:YAG laser (Deka, Italy) with 2940nm wavelength was used according to the following parameters: output power of 2W, pulse repetition rate of 20 Hz, energy density of 100mJ and 60s laser radiation time for each sample. The laser beam was aligned perpendicular to the zirconia disc surface at 5mm distance. The entire surface of the specimens was scanned manually with the laser beam while being cooled with water and air. After preparing the surfaces, Z-Prime Plus (Bisco, Schaumburg, USA) primer was applied for bonding to composite resin. For preparation of the composite cylinders, glass tubes were used with an internal cross sectional area of 5mm [27]. The tubes were filled with Z350 XT composite resin (3M, Unitek, CA, USA). The bonding of composite cylinders to the zirconia surfaces was performed using Variolink N (Ivoclar Vivadent, Liechtenstein, Germany) resin cement. One operator performed all the procedures.

Thermocycling:

All specimens were thermocycled in a thermocycler (Dorsa, Tehran, Iran) for 1000 cycles at 5-55°C with 20s of dwell time in each water bath and 20s of transfer time. Then, the specimens were stored in an incubator (Pars Azma, Tehran, Iran) at 37°C and 100% humidity for 24h. After these steps, the samples were randomly divided into three equal groups and subjected to three types of pressure conditions: I: low pressure (vacuum), II: normal pressure (1 atm) and III: high pressure (2atm).

SBS test:

The SBS of zirconia to composite was measured using a universal testing machine (Instron Z020; Zwick Roell, Ulm, Germany). The load was applied at a crosshead speed of 0.5 mm/min to the zirconia-composite interface. Load was applied until fracture, and the load at fracture was recorded in Newtons (N). The SBS values were reported in megapascals (MPa).

Statistical analysis:

The Kolmogorov-Smirnov test was used to assess the normal distribution of the data. In addition, the Levene's test was used to assess the equality of variances. Comparisons of different pressures were done for each surface treatment method using one-way ANOVA (α=0.05).

RESULTS

In this study, a total of 15 samples were evaluated in each of the groups. Table 1 demonstrates the mean SBS of the different groups.

Table 1. Mean shear bond strength (MPa) and standard deviation values in the different groups (n=15)

Surface treatment	Pressure	Mean SBS	SD
Sand-blast	Normal	6.96	2.29
	High	6.66	1.67
	Low	6.75	1.68
Laser	Normal	4.83	2.00
	High	4.16	1.16
	Low	4.23	1.34
Tribochemical	Normal	8.10	2.42
	High	6.94	1.66
	Low	6.76	1.59

SBS: shear bond strength; SD: standard deviation

The mean SBS in sandblasting, tribo-chemical preparation, and laser groups was separately compared under different pressures. No significant difference was found in SBS at different pressures in any of the three surface treatment groups (P>0.05). The results of the current investigation revealed that the effect of surface treatment on SBS was significant (P<0.001), but the effect of pressure change on this variable was not significant (P>0.05).

Based on the findings of the present study, there was a significant difference in SBS between laser surface treatment and sandblasting (P<0.001). In addition, the SBS in the laser surface treatment group was significantly different from that of the tribochemical preparation group (P<0.001). We did not observe a significant difference between the sandblasting and tribochemical preparation groups (P=0.640, Table 2).

Table 2. Effects of surface treatment on shear bond strength

Surface treatment (I)	Surface treatment (J)	Mean Difference (I-J)	Standard Error	P
Sandblast	Tribochemical	-0.476	0.38	0.640
	Laser	2.402	0.38	<0.001
Tribochemical	Laser	2.878	0.38	<0.001

According to the findings, no significant difference was found in SBS between different pressures (P>0.05). Evaluation of the interaction effect of each pressure (normal, high, and low) and surface treatment (sandblasting, tribochemical preparation, and laser) on SBS indicated that under normal pressure, the SBS was higher in the sandblasting and tribochemical preparation groups than laser (P<0.05). However, the SBS was not significantly different between the sandblasting and tribochemical preparation groups (P>0.05). The results at high and low pressures were similar to those under normal pressure (Table 3).

DISCUSSION

In the recent years, use of zirconia ceramic in dentistry, especially for the fabrication of crowns, has widely increased due to its unique mechanical properties. The main problem with the application of zirconia is lack of a strong bond between the cements and zirconia [2-9]. Also, atmospheric pressure variations can further decrease the bond strength. Therefore, this study evaluated the changes in pressure as a factor that can affect the bond strength.

According to the findings of the present study, the sandblasting group exhibited no difference in SBS under normal, high and low pressures. The same findings were obtained in the tribochemical preparation and laser preparation groups.

Among the surface treatment methods, sandblasting and tribochemical preparation methods yielded higher SBS than laser, and no difference was found between them in terms of SBS.

In the current study, the effects of pressure (normal, high, and low) and surface treatment (sandblasting, tribochemical preparation, and laser) on SBS were investigated. The results showed that under normal pressure, SBS was higher in the sandblasting and tribochemical preparation groups compared with the laser group; however, there was no difference between the sandblasting and tribochemical preparation groups. Findings at high and low pressures were similar to normal pressure. In the present investigation, efforts were made to identify the confounding factors and standardize the conditions such as composite type, environment, and surface treatment conditions in each group.

Table 3. Interaction effect of pressure and surface treatment on shear bond strength

Pressure	Surface treatment (I)	Surface treatment (J)	Mean Difference (I-J)	P
Normal	Sandblast	Tribochemical	-1.133	0.088
		Laser	2.133*	0.002
	Tribochemical	Laser	3.267*	<0.001
High	Sandblast	Tribochemical	-0.287	0.664
		Laser	2.553*	<0.001
	Tribochemical	Laser	2.840*	<0.001
Low	Sandblast	Tribochemical	-0.007	0.992
		Laser	2.520*	<0.001
	Tribochemical	Laser	2.527*	<0.001

Therefore, the differences can be attributed to the type of surface treatment and atmospheric pressure. In this study, we used Z-Prime Plus which is a resin primer containing MDP monomer. According to the results of previous studies, MDP-containing monomers such as Z-Prime Plus can chemically bond to zirconia surface [27-30].

For zirconia surface sandblasting, 50µm alumina particles were used at 10mm distance from the surface for 10s. Zirconia surface sandblasting may cause cracks in the zirconia; therefore, most studies applied 50 µm alumina particles to prepare the surface [31,32]. However, there were differences in the duration of sandblasting and the distance from the ceramic surface.

Different lasers are used to prepare the tooth or restoration surfaces. However, the mechanism of action for all of them is to roughen the surface. Er:YAG laser is the most common type of laser used for this purpose [20,33]. In the present study, Er:YAG laser was also used for surface treatment. The reaction between the water in the surface of the ceramic and the laser beam causes small explosions and evaporation at this level, and this process eliminates the material from the surface, leading to subsequent roughening of the surface. Most studies have demonstrated that the SBS generated by sandblasting is higher [34]; while, another study reported that the bond strength of Er:YAG laser was much greater than that caused by sandblasting [35]. In this study, in line with most other studies [8,9,18], the SBS of sandblasting and tribochemical preparation groups was significantly higher than that of Er:YAG laser group.

In a similar study, Taniş and Akçaboy [34] examined the effect of surface treatment in presence of MDP monomer on SBS of zirconia surface to cement. Unlike our study, their study was conducted only under normal pressure conditions (1atm). However, the results of their study were similar to the results of our study; they indicated that tribochemical silica coating was a favorable technique for a strong bond between zirconia and resin cement. MDP monomer was capable of enhancing the bond strength of sandblasted zirconia.

Yi et al. [36] compared the effect of sandblasting and tribochemical preparation and found that Z-Prime Plus treatment after air-abrasion process produced higher SBS than the group without the Z-Prime Plus after tribochemical process. In the present study, Z-Prime Plus treatment after tribochemical process produced higher SBS than Z-Prime Plus treatment after air-abrasion process; although this difference was not significant. Yassaei et al. [37] assessed the SBS of orthodontic brackets bonded to porcelain using Er:YAG laser in comparison with hydrofluoric acid. They indicated that Er:YAG laser as a favorable method was capable of bonding orthodontic brackets to porcelain surfaces. The groups received 1.6, 2, 3.2 and 4W Er:YAG laser in their study. They initially observed that the ceramic surface was burned using Er:YAG laser with 4W power and therefore it is not suitable for surface treatment. In the present study, Er:YAG laser was used with a power of 2W. The results of their study showed that the highest bond strength belonged to the sandblasting group, which was consistent with the results of the present study. In a study by Topcuoglu et al, [38] 3W laser with 20Hz frequency was used. The results of this study revealed that sandblasting created the highest bond strength amongst the tested surface treatment methods, which is consistent with the present study results. It was also shown that laser alone cannot be a suitable method for surface treatment, because all samples that underwent laser preparation were debonded during the thermocycling process. Also, laser was able to create a proper bond strength, which could be due to the use of MDP-containing monomers resulting in creation of a chemical bond. The aforementioned study indicated that the primer used did not contain MDP. The results also demonstrated that the use of laser after surface sandblasting not only does not increase the bond strength, but also decreases the bond strength due to the removal of surface roughness caused by sandblasting. In the current study, this surface treatment (use of laser after sandblasting) was not performed.

CONCLUSION

Under the limitations of this study, our results indicated greater SBS of zirconia ceramic to composite following sandblasting and tribochemical preparation of zirconia surface compared with Er:YAG laser irradiation. But different pressures had no significant effect on SBS.

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CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Thompson JY, Stoner BR, Piascik JR, Smith R. Adhesion/cementation to zirconia and other non-silicate ceramics: where are we now? Dent Mater. 2011 Jan;27(1):71-82.
2. Ferraris M, Verné E, Appendino P, Moisescu C, Krajewski A, Ravaglioli A, et al. Coatings on zirconia for medical applications. Biomaterials. 2000 Apr;21(8):765-73.
3. Blatz MB, Sadan A, Arch GH Jr, Lang BR. In vitro evaluation of long-term bonding of Procera AllCeram alumina restorations with a modified resin luting agent. J Prosthet Dent. 2003 Apr;89(4):381-7.
4. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999 Jan;20(1):1-25.
5. Guazzato M, Quach L, Albakry M, Swain MV. Influence of surface and heat treatments on the flexural strength of Y-TZP dental ceramic. J Dent. 2005 Jan;33(1):9-18.
6. Yang B, Barloi A, Kern M. Influence of air-abrasion on zirconia ceramic bonding using an adhesive composite resin. Dent Mater. 2010 Jan;26(1):44-50.
7. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res. 2013 Oct;57(4):236-61.
8. Attia A, Lehmann F, Kern M. Influence of surface conditioning and cleaning methods on resin bonding to zirconia ceramic. Dent Mater. 2011 Mar;27(3):207-13.
9. Inokoshi M, De Munck J, Minakuchi S, Van Meerbeek B. Meta-analysis of bonding effectiveness to zirconia ceramics. J Dent Res. 2014 Apr;93(4):329-34.
10. McLaren EA, Giordano RA. Zirconia-based ceramics: material properties, esthetics and layering techniques of a new veneering porcelain, VM9. Quintessence Dent Technol. 2005;28:99-111.
11. Raigrodski AJ. Contemporary all-ceramic fixed partial dentures: a review. Dent Clin North Am. 2004 Apr;48(2):viii, 531-44.
12. 12. Miller JD, Hoh KP, Ishida H. Studies of the simulation of silane coupling agent structures on particulate fillers; the pH effect. Polym Compos. 1984 Jan;5(1):18-28.
13. Lee JH, Lee M, Kim KN, Hwang CJ. Resin bonding of metal brackets to glazed zirconia with a porcelain primer. Korean J Orthod. 2015 Nov;45(6):299-307.
14. Boudrias P. The yttrium tetragonal zirconia polycrystals (Y-TZP) infrastructure: The new chapter in the search for a metal framewor replacement. J Dent Québec. 2005;42:172-6.
15. Komine F, Blatz MB, Matsumura H. Current status of zirconia-based fixed restorations. J Oral Sci. 2010 Dec;52(4):531-9.
16. Dérand P, Dérand T. Bond strength of luting cements to zirconium oxide ceramics. Int J Prosthodont. 2000 Mar-Apr;13(2):131-5.
17. Akgungor G, Sen D, Aydin M. Influence of different surface treatments on the short-term bond strength and durability between a zirconia post and a composite resin core material. J Prosthet Dent. 2008 May;99(5):388-99.
18. Cheng H, Dong C, Zhang FQ. Influence of tribochemical silica coating on shear bond strength of a dental zirconia ceramic to resin cements. Shanghai Kou Qiang Yi Xue. 2018 Jun;27(3):248-251.
19. Dilber E, Yavuz T, Kara HB, Ozturk AN. Comparison of the effects of surface treatments on roughness of two ceramic systems. Photomed Laser Surg. 2012 Jun;30(6):308-14.
20. Yavuz T, Özyılmaz ÖY, Dilber E, Tobi ES, Kiliç HŞ. Effect of different surface treatments on porcelain-resin bond strength. J Prosthodont. 2017 Jul;26(5):446-54.
21. Cavalcanti AN, Foxton RM, Watson TF, Oliveira MT, Giannini M, Marchi GM. Bond strength of resin cements to a zirconia ceramic with different surface treatments. Oper Dent. 2009 May-Jun;34(3):280-7.
22. Eduardo Cde P, Bello-Silva MS, Moretto SG, Cesar PF, de Freitas PM. Microtensile bond strength of composite resin to glass-infiltrated alumina composite conditioned with Er,Cr:YSGG laser. Lasers Med Sci. 2012 Jan;27(1):7-14.

23. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short-term in-vivo evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res. 1989 Jan;23(1):45-61.
24. Cavalcanti AN, Foxton RM, Watson TF, Oliveira MT, Giannini M, Marchi GM. Bond strength of resin cements to a zirconia ceramic with different surface treatments. Oper Dent. 2009 May-Jun;34(3):280-7.
25. Uo M, Sjögren G, Sundh A, Watari F, Bergman M, Lerner U. Cytotoxicity and bonding property of dental ceramics. Dent Mater. 2003 Sep;19(6):487-92.
26. Lee DJ, Shin IJ. Effects of vacuum, mold temperature and cooling rate on mechanical properties of press consolidated glass fiber/PET composite. Composites Part A: Appl Sci Manuf. 2002 Aug;33(8):1107-14.
27. Tanış MÇ, Akay C, Karakış D. Resin cementation of zirconia ceramics with different bonding agents. Biotechnol Biotechnol Equip. 2015 Mar;29(2):363-7.
28. Lüthy H, Loeffel O, Hammerle CH. Effect of thermocycling on bond strength of luting cements to zirconia ceramic. Dent Mater. 2006 Feb;22(2):195-200.
29. Łagodzińska P, Bociong K, Dejak B. Influence of primers' chemical composition on shear bond strength of resin cement to zirconia ceramic. Polim Med. 2014 Jan-Mar;44(1):13-20.
30. Sharafeddin F, Shoale S. Effects of universal and conventional MDP primers on the shear bond strength of zirconia ceramic and nanofilled composite resin. J Dent (Shiraz). 2018 Mar;19(1):48-56.
31. Lee JY, Kim JS, Hwang CJ. Comparison of shear bond strength of orthodontic brackets using various zirconia primers. Korean J Orthod. 2015 Jul;45(4):164-70.
32. Kwak JY, Jung HK, Choi IK, Kwon TY. Orthodontic bracket bonding to glazed full-contour zirconia. Restor Dent Endod. 2016 May;41(2):106-13.
33. Yassaei S, Moradi F, Aghili H, Kamran MH. Shear bond strength of orthodontic brackets bonded to porcelain following etching with Er:YAG laser versus hydrofluoric acid. Orthodontics (Chic.). 2013;14(1):e82-7.
34. Tanış MÇ, Akçaboy C. Effects of different surface treatment methods and MDP monomer on resin cementation of zirconia ceramics an in vitro study. J Lasers Med Sci. 2015 Fall;6(4):174-81.
35. Akın H, Ozkurt Z, Kırmalı O, Kazazoglu E, Ozdemir AK. Shear bond strength of resin cement to zirconia ceramic after aluminum oxide sandblasting and various laser treatments. Photomed Laser Surg. 2011 Dec;29(12):797-802.
36. Yi YA, Ahn JS, Park YJ, Jun SH, Lee IB, Cho BH, et al. The effect of sandblasting and different primers on shear bond strength between yttria-tetragonal zirconia polycrystal ceramic and a self-adhesive resin cement. Oper Dent. 2015 Jan-Feb;40(1):63-71.
37. Yassaei S, Aghili HA, Davari A, Mostafavi SM. Effect of four methods of surface treatment on shear bond strength of orthodontic brackets to zirconium. J Dent (Tehran). 2015 Apr;12(4):281-9.
38. Topcuoglu T, Oksayan R, Topcuoglu S, Coskun ME, Isman NE. Effect of Er:YAG laser pulse duration on shear bond strength of metal brackets bonded to a porcelain surface. Photomed Laser Surg. 2013 Jun;31(6):240-6.