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Effect of Er:YAG Laser Application and Sandblasting on Shear Bond Strength of Veneering Ceramic to Zirconia Core

Behnaz Ebadian[1], Alireza Moazami[2], Mohammad Jowkar[3*]

1. Department of Prosthodontics, Dental Implants Research Center, Dental Research Institute, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran
2. Department of Prosthodontics, School of Dentistry, Zahedan University of Medical Sciences, Zahedan, Iran
3. Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

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**** Corresponding author:***
Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

Email: mohammad.jokar90@yahoo.com

A B S T R A C T

Objectives: Porcelain chipping and delamination are among the shortcomings of all-ceramic restorations. This study aimed to assess the effect of laser irradiation and sandblasting on shear bond strength (SBS) of zirconia to veneering porcelain.

Materials and Methods: In this in vitro, experimental study, 60 zirconia blocks were randomly divided into three groups (n=20) for surface treatment with Er:YAG laser, sandblasting, and no surface treatment (control). Each group was randomly divided into two subgroups (n=10) for porcelain application by the layering or the pressing technique. The surface roughness, SBS, and failure mode were determined and analyzed using two-way ANOVA, Tukey's HSD test, Chi-square test, and Pearson's correlation test (alpha=0.05).

Results: The mean SBS was 8.16±3.66 MPa, 9.32±2.7 MPa, and 11.85±3.06 MPa in the control, laser, and sandblasting groups, respectively. The SBS was significantly different among the three groups (P=0.002). The failure mode of the three groups was not significantly different (P>0.05). The sandblasted group showed significantly higher surface roughness than the control and laser groups (P<0.001).

Conclusion: Sandblasting yielded higher SBS particularly when the porcelain was applied by the layering technique. Although laser irradiation increased the SBS, the difference with the control group was not statistically significant.

Keywords: Yttria Stabilized Tetragonal Zirconia; Air Abrasion, Dental; Lasers, Solid-State; Shear Strength

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INTRODUCTION

All-ceramic restorations are increasingly used as a more esthetic alternative to metal-ceramic restorations [1]. In all-ceramic zirconia systems, the core is fabricated by the computer-aided design and computer-aided manufacturing systems. The core is then veneered with porcelain using the layering technique or the pressing technique. Consequently, the zirconia core provides optimal support for the veneering porcelain [2]. However, limitations such as the weak bond strength of the veneering porcelain to the zirconia core can cause porcelain delamination and exposure of the zirconia core, or chipping of the veneering porcelain, which could result in failure of zirconia restorations [3]. The adhesive mode of fracture has been reported to have a prevalence of 3%-8% [4-6]. A previous study reported that the prevalence of porcelain chipping in zirconia restorations was much higher than that in metal-ceramic restorations [5]. Chipping of the porcelain may occur due to inadequate support of the veneering, inappropriate framework design, inadequate thickness of porcelain, inappropriate direction, frequency, and intensity of occlusal loads, defects in the ceramic, residual stresses due to the difference in coefficients of thermal expansion, or poor wetting of the core with porcelain [7,8].

The bonding mechanism of porcelain to zirconia core has not been fully understood, but micromechanical interactions are believed to play a role in this respect [2]. It has been reported that the bond strength of porcelain to zirconia core is weak, despite the high strength of zirconia [9]; this makes the veneering porcelain susceptible to fracture [4]. Several zirconia surface treatments have been suggested to enhance the bond strength of veneering porcelain to zirconia core, such as laser etching and sandblasting [9,10]. Aluminum oxide ($Al2O3$) sandblasting has the ability to enhance the surface energy, surface area, and wettability for a proper adhesion [9]. Surface treatment increases the bonding surface area and subsequently the bond strength [9].

Erbium-doped yttrium aluminum garnet (Er:YAG) laser with 2940nm wavelength has many clinical applications in removal of carious dentin and cavity preparation [11]. Laser etching of zirconia surface was recently introduced as an easy and safe method to increase surface roughness and shear bond strength (SBS) [12]. A few researchers evaluated the effect of laser etching of zirconia surface on its bond strength to resin cement and veneering porcelain, and reported controversial results [13,14].

Sandblasting has also been suggested to enhance the bond strength of zirconia to porcelain.

Liu et al. [15] assessed the SBS of veneering ceramic to zirconia core following surface treatment with laser and sandblasting, and reported their comparable efficacy.

Studies on the efficacy of different zirconia surface treatments have failed to introduce an ideal surface treatment for this purpose. Considering the controversy in this respect, and the increasing use of all-ceramic restorations, this study aimed to assess the effect of laser irradiation and sandblasting, as two commonly used surface treatments, on SBS of veneering ceramic to zirconia core. The surface roughness and mode of failure were also determined. The null hypothesis of the study was that there would be no significant difference between the two methods of surface treatment in SBS of veneering ceramic to zirconia core.

MATERIALS AND METHODS

This in vitro, experimental study was conducted on 60 pre-sintered yttria-stabilized zirconia blocks measuring 5mm x 10mm x 10mm (Ceramill ZI; Amann Girrbach, Koblach, Austria). The blocks were milled from zirconia blanks using a computer-aided design/ computer-aided manufacturing system (CORiTEC 340i; Imes-icore GmbH, Eiterfeld, Germany). The samples were polished with 600-, 800- and 1200-grit silicon carbide abrasive papers (Sof-Lex; 3M ESPE Co., St. Paul, MN, USA) in a finishing and polishing machine (Buehler Metaserv 2000; Buehler UK Ltd., Coventry, England) under water coolant for 15 seconds according to the manufacturer's instructions (300/min). All samples were then sintered at 1500°C for 8 hours in a furnace (Programat EP 5000; Ivoclar Vivadent, Liechtenstein), and were randomly divided into three groups of 20. Each group was divided into two subgroups of 10 for porcelain application with the layering or the pressing technique. The three main groups (n=20) were as follows:

Control group: No surface treatment was performed.

Sandblasting group: The surface of specimens was subjected to sandblasting with 120µm aluminum oxide particles under 2 bar pressure for 15 seconds at 10mm distance.

Laser group: The surface of specimens was subjected to 6W Er:YAG laser (Fidelis Plus III; Fotona, Ljubljana, Slovenia) with 2940nm wavelength. The optic fiber (600µm diameter and 6mm length) was positioned perpendicular to the surface of the specimens. Pulse duration was 140-200µs, and the repetition rate was 20 Hz. Laser was irradiated with 6W energy, and water/air ratio of 55% to 65% used after 20 seconds of laser irradiation at 10mm distance. The surface of zirconia blocks was directly subjected to laser irradiation for three times.

After each time of laser irradiation, the blocks were rotated clockwise by 90 degrees. The time interval between each two laser irradiation cycles was 20 seconds.

Assessment of surface roughness:

After surface treatment, the surface roughness (Ra parameter) of each block was measured in micrometers (µm) by a profilometer (Surftest SJ-201P Surface Roughness Tester; Mitutoyo Co., Tokyo, Japan). Ten measurements were made at different points on the surface of each specimen, and the mean of 10 measurements was calculated and recorded as the surface roughness value of the respective specimen. Also, one specimen from each group was selected for scanning electron microscopic (SEM) assessment.

SEM analysis:

One specimen was randomly chosen from each group, and gold sputter-coated (Polaron Range SC 7620; Quorum Technology, Newhaven, UK). The surface topography of the specimens was evaluated under a SEM (XL30 CP; Philips, Eindhoven, Netherlands) at x5000 magnification.

Porcelain veneering:

The specimens were inspected under a stereomicroscope (SMZ 800, Nikon, Tokyo, Japan) at x15 magnification to ensure absence of defects. After surface treatment, porcelain powder (VITA VM9; Vita Zahnfabrik. Bad Sackingen, Germany) was applied by the layering technique in 10 specimens of each group. For this purpose, the zirconia blocks were placed in an adjustable plexiglass mold, which provided a space with 5mm diameter and 3mm height above the core. The mold was filled with ceramic powder, which was condensed using an ultrasonic device. The porcelain was then sintered in a furnace (Programat EP 5000; Ivoclar Vivadent, Liechtenstein) according to the heating protocol recommended by the manufacturer. To compensate for porcelain shrinkage during sintering, two separate baking protocols were performed under the same conditions to obtain adequate dimensions and thickness of specimens. In the remaining specimens (n=10), to obtain an equal thickness of porcelain on the entire surface of all zirconia discs, heat-press ceramic (VITA PM9) was used. First, discs were ultrasonically cleaned with 10% isopropyl alcohol for 10 minutes. Next, a cylindrical wax (5mm × 3mm) was waxed-up on the discs using a plexiglass mold to reach the same shape and size of the porcelain cylinder, and then invested in a ring as recommended by the manufacturer (PM Investment Material; Vita Zahnfabric, Bad Sackingen, Germany). After wax-up, wax sprues with 3-8mm length and a minimum of 4mm diameter were attached to the wax cylinder. The rings were placed in an oven (Kavo EWL type 5615; Elektrotechnisches Werk GmbH, Germany) for wax burn-out. The temperature and time were adjusted according to the manufacturer's instructions. The rings were immediately transferred from the preheating furnace to the press oven. Ceramic (VITA PM9; Vita Zahnfabrik. Bad Sackingen, Germany) was injected into the mold as recommended by the manufacturer. Next, the surface of the specimens was inspected under a ×15 magnifier. The dimensions of the specimens were subsequently standardized by finishing, and measured using a digital caliper (Absolute 500, Kitutoyo, Aura, IL, USA). All specimens were then subjected to 20,000 thermal cycles between 5-55°C with a 30-second dwell time [8].

SBS testing:

The specimens were cleaned in an ultrasonic bath for 3 minutes, and stored in distilled water at 37°C for 24 hours. The specimens were mounted on an acrylic resin jig (Meliodent, Heraeus Kulzer GmbH, Hanau, Germany) using a surveyor such that the highest level of the jig was at the level of the core-veneering interface. Shear loads were applied as close as possible to the core-veneering interface in a universal testing machine (K-21046; Walter+Bai Co., Lohringen, Switzerland) at a crosshead speed of 1mm/minute until fracture (Fig 1). Load at fracture was recorded (N) and converted to Megapascals (MPa) using the following formula: SBS (MPa) = L/S where L = load (N), and S = surface area (mm^2).

Mode of failure:

To analyze the mode of failure, the surface of the specimens was evaluated under a stereomicroscope (SMZ 800, Nikon, Tokyo, Japan) at x32 magnification. The mode of failure was divided into three groups: adhesive, cohesive, mixed. Adhesive failure was defined.

Fig 1. Applying Shear loads to the core-veneering interface in a universal testing machine

defined as complete separation of the veneering porcelain from the zirconia core. Cohesive failure was defined as fracture within the veneering porcelain only, and mixed failure was defined as a combination of both adhesive and cohesive failures.

Statistical analysis:

Two-way ANOVA was used for general comparison of the three groups and the two techniques, followed by the Tukey's HSD post-hoc test for pairwise comparisons. The Pearson's correlation coefficient was applied to assess the possible correlations between the surface roughness and SBS. The Chi-square test was used to compare the mode of failure among the three groups. Level of statistical significance was set at 0.05.

RESULTS

The mean surface roughness was 0.73±0.09 in the control group, 0.74±0.09 in the laser group, and 1.04±0.14 in the sandblasted group. According to one-way ANOVA, the difference in surface roughness was statistically significant among the three groups ($P<0.001$). The Tukey's HSD test showed that the surface roughness of the control group was not significantly different from that of the laser group ($P=0.98$) but was significantly lower than that of the sandblasted group ($P<0.001$). The surface roughness of the laser and sandblasted groups was significantly different ($P<0.001$), and the sandblasted group showed significantly higher surface roughness.

Figures 2a, 2b and 2c show the SEM micrographs of the specimen surface in the sandblasted, laser, and control groups, respectively. According to two-way ANOVA, the three groups were significantly different in terms of SBS ($P=0.002$). The effect of porcelain application technique (layered/ press, $P=0.476$) and the interaction effect of group and technique ($P=0.256$) were not significant on SBS.

According to the Tukey's HSD test, the difference between the control and laser groups was not significant in this respect ($P=0.485$), but the mean SBS of the sandblasted group was significantly higher than that of the control group ($P=0.001$) and laser group ($P=0.037$). The SBS of the specimens in the two porcelain application subgroups of the three groups is presented in Figure 3.

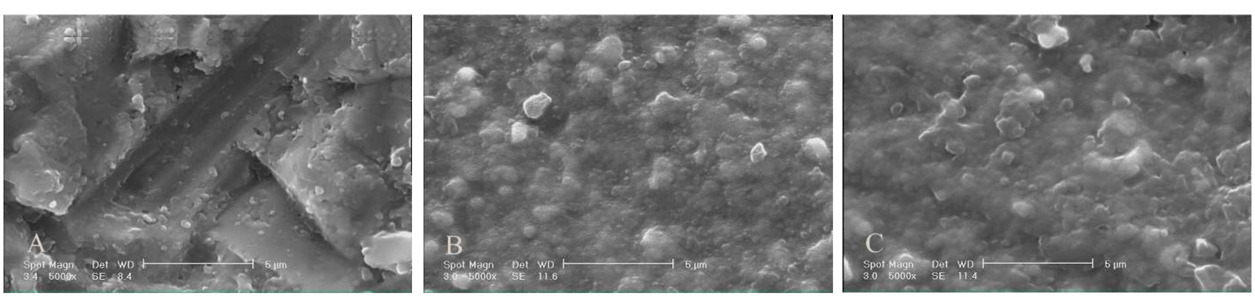

Fig 2. Electron microscopic micrographs of the fracture surface in the sandblasted (a), laser (b), and control (c) groups

A correlation was found between the surface roughness and SBS (r=0.28), which was significant according to the Pearson's correlation coefficient (P=0.028).

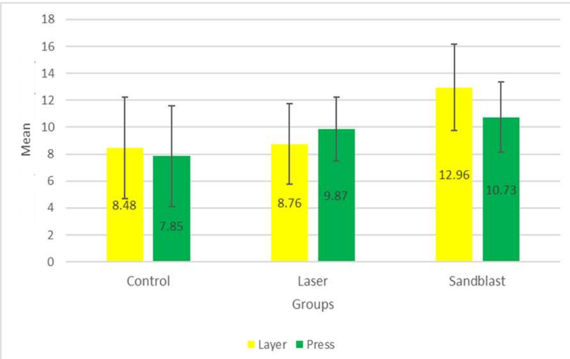

Fig 3. Mean SBS of the three groups in the layered and pressed porcelain application techniques

Figure 4 shows the frequency of different modes of failure in the three groups. According to the Chi-square test, the difference among the three groups was not significant in this respect (P=0.09).

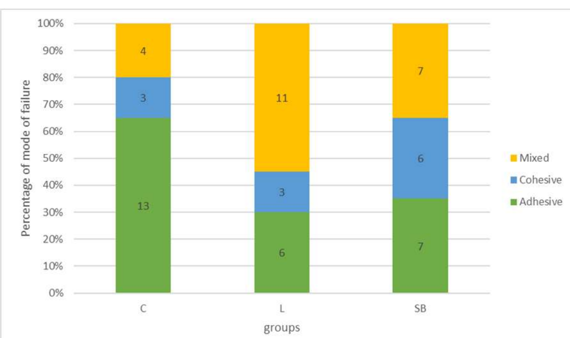

Fig 4. Frequency distribution of the modes of failure in the three groups (N=20) (C: control, L: laser, SB: sandblasting)

DISCUSSION

Based on the results of the present study, surface treatment of zirconia specimens had a significant effect on SBS; thus, the null hypothesis of the study was rejected. The method of laser application in the present study was different from previous studies, and laser was applied 3 times in different directions such that the blocks were rotated clockwise by 90 degrees after each laser irradiation cycle. Also, 2 different methods of porcelain application were evaluated in the present study, which is different from the methodology of previous studies. The authors hypothesized that porcelain application technique combined with different surface treatments may affect the bond strength.

Sandblasting of zirconia in the layered porcelain group yielded the highest SBS. Also, the results showed that the mean surface roughness in the sandblasting group was significantly higher than that in the laser and control groups.

Surface treatment is performed to remove the debris and impurities, and increase the surface roughness of zirconia [16]. The mechanism of bonding of porcelain to zirconia has not been well understood, and it is believed to be purely micromechanical [2]. Wettability and surface roughness are believed to play a role in this regard [2]. Higher bond strength in the sandblasted group in the present study is justified by the higher surface roughness in this group. Also, sandblasting cleans the surface and subsequently improves wettability. Sand-blasting is among the most common surface treatments recommended by many dental zirconia manufacturers. However, sandblasting may affect the mechanical properties and durability of zirconia since it results in formation of a compressed layer on the zirconia surface, which increases its flexural strength following tetragonal to monoclinic phase transformation [17]. Although the monoclinic phase is limited to the outer layer to a depth of 0.33μm, such a phase transformation and formation of cracks and defects during the process of sandblasting may jeopardize the long-term clinical service and durability of zirconia restorations [18,19]. A previous study showed that sandblasting pressure is important in this regard. Thus, low pressure was applied in the present study to minimize adverse effects. In the current study, sandblasting yielded the highest surface roughness and SBS. However, higher powers of Er:YAG laser or other types of laser may yield comparable or more favorable results and should be evaluated in future studies [16]. The present results regarding higher surface roughness and consequently higher SBS in the sandblasted group compared to the laser and control groups were in agreement with those of some previous studies [10,20].

Liu et al. [15] compared sandblasting with CO2 laser and reported different results from the present findings. They showed that both methods equally increased the surface roughness and bond strength. This may be due to using different laser types and zirconia brands. Evidence shows that type of zirconia affects the bond strength [10]. Thus, use of different laser types, higher power, and different types of zirconia may yield different results. Akin et al. [22] evaluated the effect of sandblasting and different powers of Er:YAG laser on SBS of resin to zirconia and showed that sandblasting and higher laser powers significantly increased the surface roughness and bond strength. They recommended Er:YAG laser as a suitable alternative to sandblasting for zirconia surface treatment [22]. Difference between their results and the present findings regarding the efficacy of laser may be due to the fact that they used higher laser powers, and duration of sandblasting was also shorter. Mosharraf et al. [21] reported that type of zirconia did not affect the SBS but method of surface treatment depended on the type of zirconia, and the interaction effect of the two on SBS was significant. Thus, the results of the present study may be related to the compatibility of sandblasting with the type of zirconia used. Clinically, many failures in zirconia-porcelain restorations occur at the zirconia-porcelain interface (adhesive failure). The main reason is inadequate support of porcelain by the zirconia core, and the weak bond between the two materials. Sandblasting increases the surface roughness and consequently the surface area of this interface and enhances the bond strength.

The SBS test was used in the present study since it is the most commonly used test for assessment of bond strength. However, data obtained by this test have a wide dispersion and the obtained values have high standard deviations.

The positive correlation of surface roughness and bond strength in the present study may be due to better compatibility of the type of zirconia used in the current study with sandblasting, and not necessarily the direct effect of increased surface roughness on bond strength. Therefore, it is important to carefully follow the manufacturers' instructions, which may vary depending on the type of zirconia. Kosmac et al. [18] compared the effects of surface roughening by sandblasting and bur on flexural strength of zirconia and reported greater increase in bond strength following sandblasting. They added that higher surface roughness does not necessarily mean higher bond strength since bur abrasion caused greater surface roughness but did not cause higher bond strength. This finding was probably due to the fact that bur preparation causes higher superficial stresses. Thus, it appears that porcelain only requires a certain level of roughness for improved bond strength, and higher values may yield unfavorable results. Amann Girrbach zirconia was used in the current study and it appears that its bond strength was correlated with the surface roughness. For this reason, higher bond strength was achieved in the sandblasted group.

The layering and pressing porcelain application techniques were compared in the current study, and the results revealed that overall, the mean SBS was not significantly different between the two techniques. However, the sandblasted subgroup showed significantly higher SBS than the other two subgroups in the layering group, but this difference was not significant in the pressed group. Similarly, Guess et al. [2] assessed the effect of porcelain application method on SBS and reported that the layering technique yielded more durable results compared to the pressing technique. It may be concluded that the layering technique, under conditions similar to those adopted in the present study, may yield more favorable results. In the pressing technique, melted porcelain is applied on the surface with pressure and thus, penetrates into the porosities. Therefore, it may yield similar bond strength to surfaces with different roughness values. This method may increase zirconia wetting irrespective of surface roughness. Thus, bond strength in this method does not depend on surface roughness. This theory was confirmed by the present findings.

In the current study, adhesive mode of failure was more common in the control group while mixed failure was dominant in the laser group. The three modes of failure had equal frequency in the sandblasted group.
Due to the in vitro design of the present study, generalization of results to the clinical setting must be done with caution. Small sample size and use of only one type of zirconia were other limitations of this study. Future studies with a larger sample size and other types of zirconia are required to better elucidate this topic.

CONCLUSION

Within the limitations of this study, the results showed that sandblasting yielded higher surface roughness and resulted in higher SBS especially in use of porcelain layering technique. Although surface treatment with laser also increased the bond strength, sandblasting was superior to laser in this respect. Surface roughness and SBS had a significant correlation. However, in the porcelain pressing technique, SBS appeared to have no correlation with surface roughness.

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CONFLICT OF INTEREST STATEMENT

The authors of this manuscript declare that they have no conflict of interests, real or perceived, financial or non-financial in this article.

REFERENCES

1. Liu P-R, Essig ME. Panorama of dental CAD/CAM restorative systems. Compend Contin Educ Dent. 2008 Oct;29(8):482, 484, 486-8 passim.
2. Guess PC, Kuliš A, Witkowski S, Wolkewitz M, Zhang Y, Strub JR. Shear bond strengths between different zirconia cores and veneering ceramics and their susceptibility to thermocycling. Dent Mater. 2008 Nov;24(11):1556-67.
3. Aboushelib MN, De Jager N, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater. 2005 Oct;21(10):984-91.
4. Anusavice KJ. Physical properties of dental materials. Phillips' science of dental materials. WB Saunders, Philadelphia, 2003:418-28
5. Fischer J, Stawarczyk B, Hämmerle C. Flexural strength of veneering ceramics for zirconia. J Dent. 2008 May;36(5):316-21.
6. Özkurt Z, Kazazoglu E, Ünal A. In vitro evaluation of shear bond strength of veneering ceramics to zirconia. Dent Mater J. 2010 Mar;29(2):138-46.
7. Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. J Dent. 2007 Nov;35(11):819-26.
8. Ben-Nissan B, Choi AH, Cordingley R. Alumina ceramics. In: Bioceramics and their clinical applications. Kokubo T edit., Woodhead Publishing LTD, Cambridge, UK, 2008:223-242.
9. Abouhelib M, Kleverlaan C, Feilzer A. Micro tensile bond strength different components of core veneered all-ceramic restoration. Dent Mater. 2006 Sep;22(9):857-63.
10. Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Effect of zirconia type on its bond strength with different veneer ceramics. J Prosthodont. 2008 Jul;17(5):401-8.
11. De Jager N, Pallav P, Feilzer AJ. The influence of design parameters on the FEA-determined stress distribution in CAD–CAM produced all-ceramic dental crowns. Dent Mater. 2005 Mar;21(3):242-51.
12. Tholey MJ, Berthold C, Swain MV, Thiel N. XRD 2 micro-diffraction analysis of the interface between Y-TZP and veneering porcelain: role of application methods. Dent Mater. 2010 Jun;26(6):545-52.
13. Kirmali O, Kustarci A, Kapdan A, Er K. Efficacy of surface roughness and bond strength of Y-TZP zirconia after various pre-treatments. Photomed Laser Surg. 2015 Jan;33(1):15-21.
14. Kirmali O, Akin H, Ozdemir AK. Shear bond strength of veneering ceramic to zirconia core after different surface treatments. Photomed Laser Surg. 2013 Jun;31(6):261-8.
15. Liu D, Matinlinna JP, Tsoi JK-H, Pow EH, Miyazaki T, Shibata Y, et al. A new modified laser pretreatment for porcelain zirconia bonding. Dent Mater. 2013 May;29(5):559-65.
16. Matinlinna JP. Adhesion Aspects in Dentistry. Leiden, Boston: Brill Academic Publication; 2009. p. 121-38.
17. Karakoca S, Yılmaz H. Influence of surface treatments on surface roughness, phase transformation, and biaxial flexural strength of Y-TZP ceramics. J Biomed Mater Res B Appl

Biomater. 2009 Nov;91(2):930-7.
18. Kosmač T, Oblak C, Jevnikar P, Funduk N, Marion L. The effect of surface grinding and sandblasting on flexural strength and reliability of Y-TZP zirconia ceramic. Dent Mater. 1999 Nov;15(6):426-33.
19. Zhang Y, Lawn BR, Rekow ED, Thompson VP. Effect of sandblasting on the long-term performance of dental ceramics. J Biomed Mater Res B Appl Biomater. 2004 Nov;71(2):381-6.
20. Kim H-J, Lim H-P, Park Y-J, Vang M-S. Effect of zirconia surface treatments on the shear bond strength of veneering ceramic. J Prosthet Dent. 2011 May;105(5):315-22.
21. Mosharraf R, Rismanchian M, Savabi O, Ashtiani AH. Influence of surface modification techniques on shear bond strength between different zirconia cores and veneering ceramics. J Adv Prosthodont. 2011 Dec;3(4):221-8.
22. 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.