

Surface Topographic Variations and Shear Bond Strength of 3Y-TZP Treated with Al_2O_3 and Nd: YAG-lasers Operating at Short Pulse

S. Alresayes*

Department Of Prosthetic Dental Science, College of
Dentistry, King Saud University, Riyadh, Saudi Arabia.

received January 29, 2025; received in revised form March 07, 2025; accepted March 08, 2025

Abstract

Aim Influence of sandblasting (SB), hydrofluoric acid (HFA) and neodymium-yttrium aluminum garnet (Nd: YAG) laser working @nanosecond (ns) level on the surface roughness (Ra) and shear bond strength (SBS) of yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) bonded to resin cement.

Methods 64 3Y-TZP discs were prepared and allocated into four groups based on the surface pretreatment method used ($n = 16$) Group 1 (No conditioning), Group 2 (SB), Group 3 (10% HFA gel) and Group 4 (ns-Nd: YAG laser). SEM was used to evaluate the surface topography following different conditioning regimes. Ra analysis was assessed on five discs from each group with a surface profilometer. Resin cement bonding was performed on ten specimens from each cohort and underwent thermocycling. SBS and failure mode were analyzed using a universal testing machine and stereomicroscope respectively. ANOVA and post hoc Tukey test were used for statistical analysis ($p < 0.05$)

Result The maximum score for Ra ($1209.54 \pm 0.06 \mu\text{m}$) and SBS ($12.21 \pm 0.15 \text{ MPa}$) was shown in Group 4 (ns-Nd: YAG laser)-conditioned discs. Group 1 (Control)-treated discs displayed minimum scores of Ra ($987.23 \pm 0.032 \mu\text{m}$) and SBS ($9.16 \pm 0.17 \text{ MPa}$)

Conclusion Nd: YAG laser working at short pulses can be a suitable alternative to SB, enhancing the SBS of 3Y-TZP bonded to resin cement by increasing Ra .

Keywords: Sandblasting, Nd:YAG laser, surface condition, SEM, failure assessment, 3Y-TZP.

I. Introduction

The use of zirconia in dental applications has increased dramatically, primarily due to rising gold costs and improvements in dental CAD/CAM technology¹. Yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) exhibits remarkable mechanical properties, including high flexural strength, resistance to fracture, visual similarity to natural teeth, and compatibility with biological systems^{1,2}. Nevertheless, attaching zirconia prosthetics to tooth structures using resin cement presents difficulties and leads to reduced shear bond strength (SBS)^{3,4}. To address this issue, it is recommended to treat the inner surface of the prosthetic before bonding it with resin cement.

Sandblasting (SB) is widely recognized as the most common method for texturing various ceramic surfaces⁵. The resulting increase in surface roughness (Ra) leads to improved bond integrity. However, SB's effectiveness depends on factors such as abrasive grain size and application distance. Despite its satisfactory clinical results, this technique has a downside. Using larger particles can compromise mechanical properties by creating fine cracks due to zirconia's phase transformation from tetragonal

to monoclinic, caused by severe thermal shock^{6,7}. This transformation significantly affects the longevity of zirconia restorations⁸. Similarly, hydrofluoric acid (HFA) treatment is another frequently used method for conditioning 3Y-TZP. It interacts with the zirconia surface, removing the silica-containing glassy matrix and exposing the crystalline phase⁹. This phase change enhances Ra , ultimately improving the shear bond strength when the zirconia is bonded to resin cement. Current literature indicates that the impact of HFA on zirconia's Ra and bond strength remains uncertain, warranting further investigation.

In addition to mechanical and chemical techniques, laser irradiation has emerged as an effective surface conditioning method for improving the Ra and SBS of ceramic bonded with bonding cement^{10,11}. The laser was initially developed in 1963 by Elias Snitzer¹². Based on the available indexed literature, research has shown that neodymium-yttrium aluminum garnet (Nd: YAG) lasers operating at short pulses, specifically at the nanosecond (ns) level, have demonstrated the ability to enhance the Ra and bond strength at the zirconia-cement interface^{13,14}. It is anticipated that utilizing laser methods with shorter pulse durations will effectively remove

* Corresponding author: salresayes@ksu.edu.sa

small amounts of material while maintaining the integrity of adjacent surfaces^{15,16} Nevertheless, the current data remains limited and inconclusive, necessitating further investigation in this area.

The present inquiry aims to investigate the influence of SB, HFA, and ns-Nd: YAG laser on the *Ra* and bond integrity of zirconia bonded to resin cement. Thus, it was assumed that there would be a significant difference in the *Ra* and SBS of 3Y-TZP bonded to resin cement when pretreated with different conditioners as compared to the non-conditioning group.

II. Materials and Methods

(1) Samples preparation

Pre-sintered 3 mol % yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) (Vatech MCIS, Hwaseong, Republic of Korea) ceramic block was used in the present inquiry. The block was sectioned by means of a cutting machine (Talmax, Curitiba-PR, Brazil) into 64 disc-shaped specimens having dimensional parameters of 5 mm diameter and 2 mm thickness. Polishing was performed with silicon carbide (SiC) papers with 400 grits followed by ultrasonic cleaning (Vitasonic, VITA Zahnfabrik, Bad Säckingen, Germany) in isopropanol for 3 mins. All the discs were rooted in self-cure acrylic resin. The discs were allocated into four groups based on the surface pretreatment method used ($n = 16$)¹⁷:

Group 1 (No conditioning) In this group, no conditioner was used.

Group 2 (SB) In this group, 3Y-TZP discs were sand-blasted with 110 μm aluminum oxide (Sandstorm, Vaniman Manufacturing Co, Fallbrook, California, US) by placing them in a specially designed holder at 2 bar pressure. The distance between the blasting tip and the specimen's surface was 10 mm and the exposure time was 15 secs¹⁸.

Group 3 (10 % HFA gel) 10 % HFA (Condac Porcelana, FGM – Joinville, Brazil) was smeared on the specimen surface for 60 secs and subsequently rinsed with an air-water spray¹⁹.

Group 4 (ns-Nd: YAG laser) The surfaces of the discs in this group were textured using a Nd-YAG laser (OEM Plus 6 W, Italy) configured to a wavelength of 1 064 nm and a frequency of 20 kHz. The surface was conditioned for 60 secs at a distance of 2 cm²⁰.

Ra analysis

The surface profilometer (Talysurf Infra 50 instrument, Tylor Hobson Ltd., Leicester, England) was calibrated to measure the roughness in micrometers (μm) ensuring that the stylus tip scans a length of 0.75 mm. Three readings were recorded at three distinct positions: parallel, perpendicular, and oblique. These average of three readings were taken as a mean score of each specimen²¹.

Surface topography analysis

A nanometer-thick layer of Au was applied on one conditioned 3Y-TZP disc from each group to facilitate the necessary surface discharge for SEM (FE-SEM; JSM-

6700F, JEOL Ltd., Akishima, Japan) characterization at electron beam acceleration voltage of 1 kV²².

Resin cement bonding

Adhesive resin was applied to the discs (Ambar, FGM, Joinville, Brazil) for 20 secs following manufacturer guidelines. This was followed by dual-cure resin cement (Allcem, FGM, Joinville, Brazil) building via a silicon mold which was placed perpendicular to the disc's intaglio surface. Specimens underwent light curing using an LED curing unit (Coltène/Whaledent, Altstätten, Switzerland) at an intensity of 1 000 mW/cm² for 40 secs. All discs were immersed in distilled water at a temperature of 37 °C for 24 hours.

Artificial aging

Thermocycling was conducted on all the bonded discs for a total of 10 000 cycles, utilizing a thermocycler (Espec Corp, United States). Each cycle consisted of 30 secs of immersion in a cold bath maintained at 5 °C, followed by 30 secs of immersion in a hot bath set at 55 °C. Each cycle consisted of 1 min total immersion in two baths with a transfer time of 30 secs in between²².

SBS analysis

A universal testing machine (UTM) (Erichsen, Wuppertal, Germany) applying a 2 kN load at a rate of 1 mm/min till the time debonding occurs was used for bond strength assessment. The applied load was measured in MegaPascals (MPa).

Failure mode analysis

The failure modes were examined using a stereomicroscope (Olympus SZ-PT-Japan) at a magnification of 60x. Failures were assessed as adhesive, cohesive, and admixed.

Data analysis

Statistical analysis was performed using a statistical package of social sciences (SPSS Inc. Chicago, IL, USA). One-way analysis of variance (ANOVA) and post hoc Tukey were used for *Ra* and SBS among investigated groups ($p < 0.05$)

III. Results

Surface topographic changes on 3Y-TZP discs: Fig. 1: A) SEM image shows micro/nanostructures on the 3Y-TZP surface created by ns-Nd: YAG laser ablation. B) SB treatment on 3Y-TZP produces an uneven, textured zirconia surface. C) SEM visualization reveals HFA-etched zirconia with a nano-irregular pattern of roughness and irregularity on one half, while the other half remains undamaged.

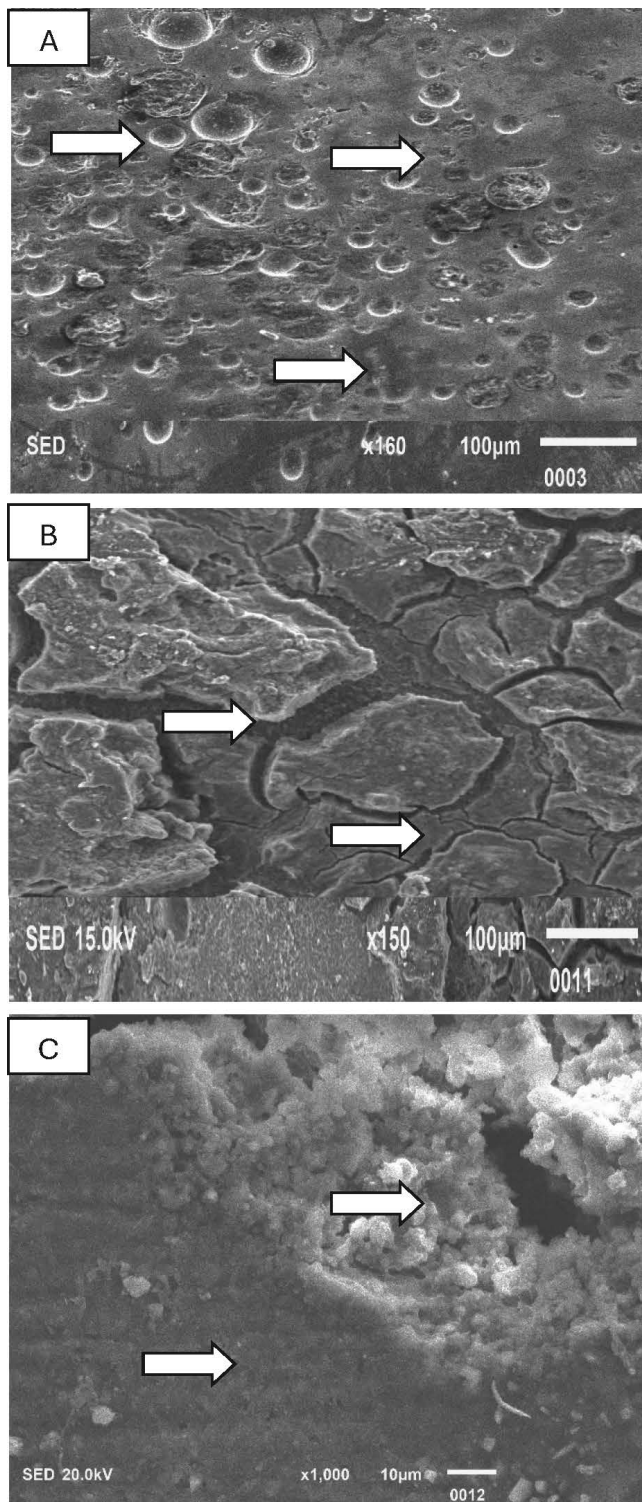


Fig. 1: A) SEM micrograph depicts ns-Nd:YAG laser ablation on 3Y-TZP resulting in the formation of micro/nanostructures on the zirconia surface (see arrows) B) SB on 3Y-TZP demonstrating textured and uneven surface on the zirconia (see arrows) C) SEM image shows HFA-etched zirconia with a nano-irregular pattern area of irregularity and surface roughness. Whereas the other half shows no damage to the zirconia surface.

Ra assessment Ra scores of 3Y-TZP discs after being pretreated with different surface conditioners are displayed in Table 1. The maximum score of Ra was shown in Group 4 (ns-Nd: YAG laser) ($1209.54 \pm 0.06 \mu m$) conditioned discs. However, Group 1 (Control) ($987.23 \pm 0.032 \mu m$)-treated discs displayed minimum scores of Ra . Com-

parative analysis among various tested groups revealed that Group 3 (SB) ($1205.12 \pm 0.051 \mu m$)-, and Group 4-pretreated discs demonstrated comparable Ra outcomes ($p > 0.05$). However, Group 2 (HFA) ($1108.31 \pm 0.023 \mu m$) presented higher scores than Group 1 yet lower than Group 3 and 4 ($p < 0.05$) (Fig. 2).

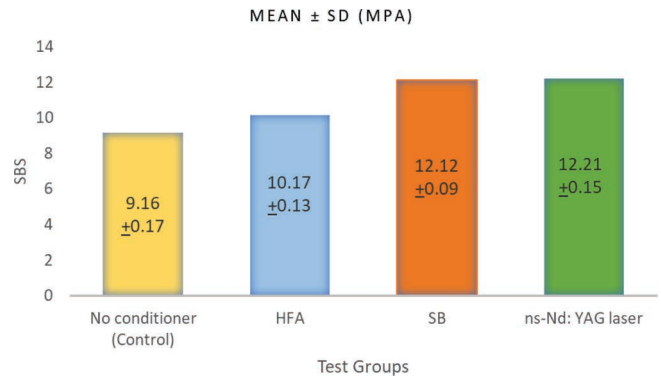


Fig. 2: Surface roughness (Ra) of 3Y-TZP following application of various conditioning agents.

Table 1: Ra of 3Y-TZP after being pretreated with different conditioners.

Tested groups	Mean $\pm$ SD (μm)	p-value!
Group 1: No conditioner (Control)	987.23 $\pm$ 0.032 ^a	
Group 2: HFA	1108.31 $\pm$ 0.023 ^a	< 0.05
Group 3: SB	1205.12 $\pm$ 0.051 ^a	
Group 4: ns-Nd: YAG laser	1209.54 $\pm$ 0.066 ^b	

!ANOVA

Hydrofluoric acid (HFA), Sandblasting (SB), Nanosecond laser (ns), Neodymium-yttrium aluminum garnet (Nd: YAG)

Different superscript small alphabets denote statistically significant differences (Post Hoc Tukey Multiple Comparison Tests)

SBS Investigation SBS of 3Y-TZP bonded to resin cement after being pretreated with different conditioners are exhibited in Table 2. Group 4 (ns-Nd: YAG laser) (12.21 ± 0.15 MPa) pretreated discs exhibited the strongest bond strength. However, Group 1 (Control) (9.16 ± 0.17 MPa) exhibited the weakest bond scores. Comparative analysis among tested groups revealed that Group 3 (SB) (12.12 ± 0.09 MPa)-, and Group 4-pretreated discs demonstrated no significant variation in SBS outcomes. ($p > 0.05$) However, Group 2 (HFA) (10.17 ± 0.13 MPa) presented higher scores than Group 1 yet lower than Group 3 and 4. ($p < 0.05$) (Fig. 3).

Fracture Analysis: Failure mode distribution among different tested groups is displayed in Fig. 4. The cohesive fracture was most observed in SB and ns-Nd: YAG laser-pretreated groups. However, HFA and control presented cohesive and admixed failures predominantly (Fig. 4).

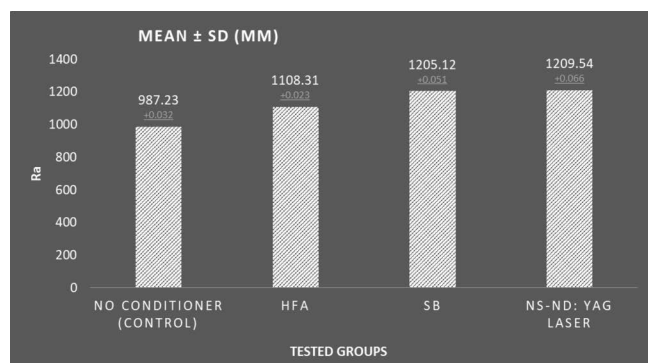


Fig. 3: Shear bond strength of 3Y-TZP bonded to resin cement following application of various surface treatments.

Table 2: SBS of 3Y-TZP bonded to resin cement after being pretreated with different conditioners.

Tested groups	Mean ± SD (MPa)	p-value!
Group 1: No conditioner (Control)	9.16 ± 0.17 ^c	
Group 2: HFA	10.17 ± 0.13 ^b	< 0.05
Group 3: SB	12.12 ± 0.09 ^a	
Group 4: ns-Nd: YAG laser	12.21 ± 0.15 ^a	

!ANOVA

Hydrofluoric acid (HFA), Sandblasting (SB), Nanosecond laser (ns), Neodymium-yttrium aluminum garnet (Nd: YAG)

Different superscript characters denote statistically significant differences (Post Hoc Tukey Multiple Comparison Test)

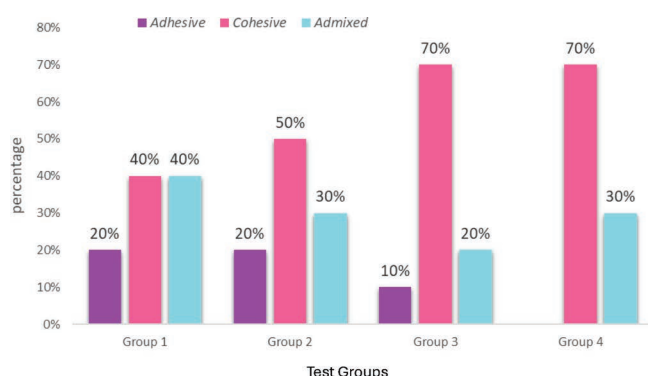


Fig. 4: Failure mode distribution in different tested groups.

IV. Discussion

The investigation was based on the hypothesis that 3Y-TZP specimens subjected to various conditioning agents would exhibit marked differences in Ra and SBS when bonded to resin cement, compared to untreated controls. The findings fully corroborated the initial suppositions, as all experimental groups exposed to the novel surface conditioners (HFA, SB, ns-Nd: YAG laser)

demonstrated enhanced Ra measurements and superior adhesion strength relative to the non-conditioned samples.

The application of ns-Nd: YAG laser on 3Y-TZP to improve Ra and enhance bonding with composite resins has been the subject of many comprehensive studies^{16,23}. However, the outcomes of these investigations have shown significant variability. Research suggests that discs treated with ns-Nd: YAG laser and SB demonstrated comparable and increased levels of Ra and SBS. These results are in line with the work of Usumez *et al.*²⁴ and Fornaini *et al.*²⁵. Their research proposed that utilizing Nd: YAG laser with brief pulses enhances Ra by creating microgrooves, pits, and material buildup, thus facilitating better resin cement infiltration and consequently strengthening the bond. SEM analysis further corroborates this observation that ns Nd: YAG laser ablation induces the formation of micro/nanostructures on the zirconia surface. Nevertheless, contradictory findings emerged from the laboratory investigation conducted by Noda and associates²⁶. They asserted that Nd: YAG laser treatment results in crack formation and reduces the oxygen content on zirconia surfaces, subsequently weakening the zirconia's mechanical properties²⁶. The inconsistency in outcomes is attributed to variations in study design, sample aging, ceramic type, and adhesive used.

Available indexed literature has revealed that SB with aluminum oxide particles is recommended as the optimal pretreatment method for enhancing bond scores of indirect ceramic materials, including alumina and zirconia ceramics²⁷. Its satisfactory performance in terms of augmenting roughness and SBS can be attributed to its phenomenon of creating a textured and uneven surface on the zirconia surface²⁸. This increases the surface energy and wettability which eventually enhances the micromechanical interlocking of the resin cement²⁹. However, its negative effect on the mechanical performance of the material cannot be ignored.

The HFA conditioning groups achieved lower bond scores, surpassing the control group, yet inferior to the scores of the ns-Nd: YAG laser and SB groups. The SEM analysis conducted in the present inquiry also revealed that HFA-etched zirconia showed a nano-irregular pattern which was also observed in the findings of Kim and coauthors³⁰. They stated that the formation of this nanopattern may be responsible for the diminished SBS, as the resin cement's high viscosity prevents it from effectively penetrating the nano-porosity of the etched-zirconia surface³⁰. Nevertheless, certain studies have indicated that Y-TZP treated with HFA does not enhance bond strength^{31,32}. Contrary to this, an *in vitro* inquiry conducted by Rego *et al.* reported that 10 % HFA modifies the surface texture and improves the bond strength between zirconia and resin cement³³. The non-pretreated group, on the other hand, exhibited the lowest scores for Ra and bond integrity. This was further supported by the SEM analysis of a surface without irregularities, thereby validating the SBS.

This investigation has several inherent constraints. As it was primarily conducted in a laboratory setting, cau-

tion should be exercised when extrapolating the results. Although Ra was evaluated, the study did not examine the volumetric porosity or average pore size of each ceramic. Such information could offer additional insights into the nature of the conditioning effect observed on ceramic surfaces. Moreover, the study relied solely on 2D SEM images. Exploring the z dimension (3-D) would provide a more comprehensive understanding of pore distribution in acid-etched ceramics. Additionally, this research did not investigate the effects of varying acid concentrations or different laser parameters, aspects that should be addressed in future studies.

V. Conclusions

The ns-Nd:YAG laser operating in short pulse mode offers a viable alternative to SB for improving the SBS of 3Y-TZP bonded to resin cement by creating a rougher surface. Nevertheless, research in this area is limited, and further investigation is necessary.

References

- Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S., Tamaki, Y.: A review of dental CAD/CAM: current status and future perspectives from 20 years of experience, *Dent. Mater. J.*, **28**, [1], 44–56, (2009).
- Thompson, J.Y., Stoner, B.R., Piascik, J.R., Smith, R.: Adhesion/cementation to zirconia and other non-silicate ceramics: Where are we now? *Dent. Mater.* **27**, [1], 71–82, (2011).
- Blatz, M.B., Sadan, A., Kern, M.: Resin-ceramic bonding: A review of the literature. *J. Prosthet. Dent.*, **89**, [3], 268–274, (2003).
- Stawarczyk, B., Basler, T., Ender, A., Roos, M., Özcan, M., Hämmerle, C.: Effect of surface conditioning with airborne-particle abrasion on the tensile strength of polymeric CAD/CAM crowns luted with self-adhesive and conventional resin cements, *J. Prosthet. Dent.*, **107**, [2], 94–101, (2012).
- Motevasselian, F., Amiri, Z., Chiniforush, N., Mirzaei, M., Thompson, V.: *In vitro* evaluation of the effect of different surface treatments of a hybrid ceramic on the microtensile bond strength to a luting resin cement, *J. Lasers Med. Sci.*, **10**, [4], 297–303, (2019).
- Sato, H., Yamada, K., Pezzotti, G., Nawa, M., Ban, S.: Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment, *Dent. Mater. J.*, **27**, [3], 408–414, (2008).
- Karakoca, S., Yilmaz, H.: Influence of surface treatments on surface roughness, phase transformation, and biaxial flexural strength of Y-TZP ceramics, *J. Biomed. Mater. Res. – Part B Appl. Biomater.*, **91**, [2], 930–937, (2009).
- Kern, M., Barloi, A., Yang, B.: Surface conditioning influences zirconia ceramic bonding, *J. Dent. Res.*, **88**, [9], 817–822, (2009).
- Aladağ, S.Ü., Ayaz, E.A.: Repair bond strength of different CAD-CAM ceramics after various surface treatments combined with laser irradiation, *Lasers Med. Sci.*, **38**, [1] (2023).
- Alkhudhairy, F., Alfawaz, Y.F.: Pretreatment of hybrid ceramics using Ho: YAG, low-level laser therapy activated malachite green, and non-thermal plasma on surface roughness, bond strength, and color change, SEM and EDX analysis, *Ceram. Int.*, **7**, [3], 944–957, (2024).
- Vohra, F., Labban, N., Al-Hussaini, A.: Influence of Er:Cr:YSGG laser on shear bond strength and color stability of lithium disilicate Ceramics: an *In Vitro* study, *Photobiomodulation, Photomedicine, Laser Surg.*, **37**, [8], 483–488, (2019).
- Koester, C.J., Snitzer, E.: Amplification in a fiber laser, *Appl. Opt.*, **3**, [10], 1182, (1964).
- Da Silveira, B.L., Paglia, A., Burnett, L.H., Shinkai, R.S.A., Eduardo, C.D.P., Spohr, A.M.: Micro-tensile bond strength between a resin cement and an aluminous ceramic treated with Nd:YAG laser, rocatec system, or aluminum oxide sandblasting, *Photomed. Laser Surg.*, **23**, [6], 543–548, (2005).
- Spohr, A.M., Borges, G.A., Burnett, L.H., Mota, E.G., Oshima, H.M.S.: Surface modification of in-ceram zirconia ceramic by Nd:YAG laser, rocatec system, or aluminum oxide sandblasting and its bond strength to a resin cement, *Photomed. Laser Surg.*, **26**, [3], 203–208, (2008).
- Ariyaratnam, M.T., Wilson, M.A., Mackie, I.C., Blinkhorn, A.S.: A comparison of surface roughness and composite/enamel bond strength of human enamel following the application of the Nd:YAG laser and etching with phosphoric acid, *Dent. Mater.*, **13**, [1], 51–55, (1997).
- Basunbul, G.I., Alzahrani, K.M., Almutairi, B., Alsunbul, H., Abduljabbar, T.: The impact of riboflavin, Nd: YAG laser, and ceramic primer pretreatment on surface roughness, bond failure, and adhesive strength of resin composite to lithium disilicate Ceramics: A scanning electron microscopy (SEM) analysis, *J. Biomater. Tissue Eng.*, **13**, [8], 882–887, (2024).
- Akyil, M.Ş., Uzun, I.H., Bayindir, F.: Bond strength of resin cement to yttrium-stabilized tetragonal zirconia ceramic treated with air abrasion, silica coating, and laser irradiation, *Photomed. Laser Surg.*, **28**, [6], 801–808, (2010).
- Kim, H.K., Ahn, B.: Effect of Al_2O_3 sandblasting particle size on the surface topography and residual compressive stresses of three different dental zirconia grades, *Materials (Basel)*, [Internet], **14**, [3], 1–19, (2021).
- Alsunbul, H., Almutairi, B., Aljanakh, M., Abduljabbar, T.: Hybrid ceramic repair strength, surface roughness, and bond failure, using methylene blue-activated low-level laser therapy, carbon dioxide, and Ti: Al_2O_3 laser, *Photodiagnosis Photodyn. Ther.*, **43**, (2023).
- Dikey, E.V., Bayindir, F.: Effect of femtosecond, Er: YAG and Nd: YAG laser systems on bond strength resin cement with esthetic post system, *Int. J. Appl. Dent. Sci.*, **6**, [4], 441–447, (2020).
- Maawadh, A.M., Almohareb, T., Al-Hamdan, R.S.: Repair strength and surface topography of lithium disilicate and hybrid resin ceramics with LLLT and photodynamic therapy in comparison to hydrofluoric acid, *J. Appl. Biomater. Funct. Mater.*, **18**, (2020).
- Alfaawaz, Y.F., Alamri, R., Almohsen, F.: Adhesive bond integrity of experimental zinc oxide nanoparticles incorporated dentin Adhesive: an SEM, EDX, μ TBS, and rheometric analysis, *Scanning*, 2022 (2022).
- Poosti, M., Jahanbin, A., Mahdavi, P., Mehrnosh, S.: Porcelain conditioning with Nd: YAG and Er:YAG laser for bracket bonding in orthodontics, *Lasers Med. Sci.*, **27**, [2], 321–324, (2012).
- Usumez, A., Hamdemirci, N., Koroglu, B.Y., Simsek, I., Parlar, O., Sari, T.: Bond strength of resin cement to zirconia ceramic with different surface treatments, *Lasers Med. Sci.*, **28**, [1], 259–266, (2013).
- Fornaini, C., Poli, F., Merigo, E. *et al.*: Nanosecond pulsed fiber laser irradiation for enhanced zirconia crown adhesion: morphological, chemical, thermal and mechanical analysis, *J. Photochem. Photobiol. B Biol.*, **219**, (2021).
- Noda, M., Okuda, Y., Tsuruki, J., Minesaki, Y., Takenouchi, Y., Ban, S.: Surface damages of zirconia by Nd:YAG dental laser irradiation, *Dent. Mater. J.*, **29**, [5], 536–541, (2010).
- Su, N., Yue, L., Liao, Y.: The effect of various sandblasting conditions on surface changes of dental zirconia and shear bond strength between zirconia core and indirect composite resin, *J. Adv. Prosthodont.*, **7**, [3], 214–223, (2015).

- ²⁸ Zandparsa, R., Talua, N.A., Finkelman, M.D., Schaus, S.E.: An *in vitro* comparison of shear bond strength of zirconia to enamel using different surface treatments, *J. Prosthodont.*, **23**, [2], 117–123, (2014).
- ²⁹ 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.*, **15**, [6], 426–433, (1999).
- ³⁰ Kim, H.E., Lim, M.J., Yu, M.K., Lee, K.W.: Changes in bond strength and topography for y-tzp etched with hydrofluoric acid depending on concentration and temperature conditions, *Med.*, **56**, [11], 1–11, (2020).
- ³¹ Sriamporn, T., Thamrongananskul, N., Busabok, C., Poolthong, S., Uo, M., Tagami, J.: Dental zirconia can be etched by hydrofluoric acid, *Dent. Mater. J.*, **33**, [1], 79–85, (2014).
- ³² You, G.E., Lim, M.J., Min, K.S., Yu, M.K., Lee, K.W.: Surface property changes observed in zirconia during etching with high-concentration hydrofluoric acid over various immersion times, *Dent. Mater. J.*, **43**, [1], 52–57, (2024).
- ³³ Steling Rego, M.E., Nunes Guimarães Paes, P., Ribeiro da Silva Schanuel, F., Mendes Jardim, P.: Acid etching and silica coating effects on Y-TZP topography and ceramic/resin cement bond strength, *Ceram. Int.*, **47**, [4], 5235–5243, (2021).