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Is the Er:YAG laser affect the surface characteristics and bond strength of Y-TZP?

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This study evaluated the surface characteristics and bond strength of Y-TZP treated with Er:YAG laser at different focal distances. 120 Y-TZP blocks were divided into five groups (n=24), according to the surface treatment: no treatment (C-); sandblasting with silica-coated aluminum oxide particles (C+); and Er:YAG laser application at focal distances of 1mm (Er:YAG-1), 4mm (Er:YAG-4), and 7mm (Er:YAG-7). Surface characteristics were analyzed using Vickers microhardness, confocal laser microscope, scanning electron microscopy (SEM), and X-ray diffractometer (XRD). For the bond strength test, 100 Y-TZP blocks were subdivided into two subgroups (n=10), according to the resin cement used: with (MDP+) or without 10-methacryloyloxydecyl dihydrogen phosphate (MDP-). The Vickers microhardness and surface roughness were analyzed by one-way ANOVA and bond strength by two-way ANOVA and Tukey's test for both (α=0.05). Vickers microhardness differences were not observed between the groups ($p>0.05$); C+ showed higher surface roughness values. SEM images showed micromorphological differences between the groups. The XRD data detected tetragonal crystals for C- and, for the other groups, tetragonal and monoclinic peaks. For bond strength, no statistically difference significance were observed among the cements with or without MDP ($p>0.05$) but showed significant difference between the surface treatments (C+ > C- = Er:YAG1 > Er:YAG4 = Er:YAG7) ($p<0.05$). Suggested that the Er:YAG laser cannot replace conventional treatment with aluminum oxide particles and the presence of MDP in the resin cement had no influence on the bond strength.

Key Words: Yttria-stabilized zirconia, surface properties, lasers, resin cements, shear strength.

Introduction

Yttria-stabilized tetragonal zirconia (Y-TZP) presents adequate biomechanical characteristics and has been considered to ensure support for metal-free restorations and to manufacture full-contour monolithic restorations (1). However, Y-TZP shows poor adesion to resin cement in comparison with vitreous ceramics (2), because of high crystalline content, absence of silica in its structure, inertia in response to etch with hydrofluoric acid, low chemical reactivity (3), and low response to the silanization methods (4).

The long-term adhesion durability at the Y-TZP-cement interface is achieved by micromechanical retention and chemical bonding between the materials (5). The sandblasting with aluminum-oxide (Al_2O_3) particles coated with silica is considered "gold standard" surface treatment of Y-TZP (3,5-7). Another promising technique for Y-TZP surface treatment is high-power laser irradiation (8,9). During irradiation, light energy is converted to heat, and its absorption at the target surface promotes changes in surface topography (9).

The erbium: yttrium aluminum garnet (Er:YAG) laser (2940 ηm) is an easy, relatively safe way to modify the surface of the material and shows versatility in the odontological clinic (10). The Er:YAG laser is indicated for etched the surface of dental materials, with the aim of increasing the surface roughness to obtain adequate bonding strength between the material and the cementing agent (11,12). Studies appointed that different lasers parameters are crucial for micromechanical interlocking and bond strength (13-16). Additionally, it is known that the focal length is directly related to the amount of energy that will focus on the surface of the substrate, and when the laser is coated on dental enamel at different focal lengths, it can cause surface ablation, fusion or only alteration of the surface (17). The literature have been contradictory (9), because there is no consensus on the interaction of the Er:YAG laser with the Y-TZP surface (13-16,18), and there is not enough scientific evidence to prove that, after the laser application, the surface will maintain its characteristics, without change it (15,20).

Cementing agents can improve the bonding strenght between Y-TZP and the substrate based in the quality of chemical interaction between the ceramic surface and the resin monomers (21). The chemical

bonding for polycrystalline ceramics involves the use of several couplers (22). According to the literature, the incorporation of bisphenol-A diglycidyl methacrylate in primers has no effect on the contact angle or the bond strength between the Y-TZP surface and the resin cement (7). However, the association of treated Y-TZP surface, primers, and resin cements containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) phosphate monomer has shown durable bond. MDP appears to produce hydrothermally stable bonds between the composite and Y-TZP, and so the bond between the MDP acid groups and the hydroxyl groups of the zirconia metal oxides, with or without surface pretreatment, is more effective (7,21,23-24).

There is no consensus on the optimal protocol for adhesive cementation of the prostheses manufactered by Y-TPZ (2). So, this study evaluated the treatment of the Y-TZP surface with Er:YAG laser at different focal distances (1, 4, and 7 mm) in relation to the Y-TZP surface characteristics and to the bond strength to different resin cements (containing or not containing MDP). The null hypotheses of this study were that (1) surface treatments would not affect the surface characteristics of Y-TZP and (2) surface treatments associated with resin cements would not affect the Y-TZP bond strength.

Materials and methods

Pre-sintered Y-TZP ceramic blocks (IPS emax ZirCAD; Ivoclar Vivadent, Schaan, Liechtenstein) were cut using a diamond blade (15LC, Buehler, Lake Bluff, IL, USA) at low speed precision cutter (Isomet 1000, Buehler, Lake Bluff, IL, USA), with constant water cooling. One hundred twenty blocks (7 mm lenght × 6.5 mm wide × 4.0 mm thick) were produced, polished with silicon carbide papers (#600 to #1200 grit size, 3M, St. Paul, MN, USA), cleaned with an isopropyl ethanol in an ultrasonic vibration (Alpha 3L Plus; Ecel Indústria e Comércio, Ribeirão Preto, SP, Brazil) for 10 min, and subjected to the sintering process (inFire HTC Speed furnace, Sirona Dental Systems, GmbH, Bensheim, Germany) according to the manufacturer's recommendation (Table 1). The final dimensions of the blocks were 5.5 mm lenght × 5.0 mm wide × 3.0 mm thick, once the pre-sintered Y-TZP underwent a contraction during the sintering process.

Table 1. Sintering process cycles of Y-TZP according manufacturer's recommended firing schedules

Parameters	Y-TZP
Initial temperature (°C)	403°C
Temperature increase (°C/min) – t_1	90°C/min
Firing temperature (°C) – T_1	800°C
Maintenence time (min) – H_1	0:10 min
Temperature increase (°C/min) – t_2	30°C/min
Firing temperature (°C) – T_2	840°C
Maintenence time (min) – H_2	7:00 min
Vacuum 1: $1_1/1_2$	550°C / 1022°C
Vacuum 2: $2_1/2_2$	820°C / 1508°C
Slow cooling (°C/min) - L	700°C

Surface treatment

Y-TZP ceramic blocks were divided into five groups (n = 24), according to the surface treatment:

1. Negative control group (C-): without surface treatment;

2. Positive control group (C+): abrasion with 110-µm silica-coated aluminum oxide particles (Rocatec, 3M/ESPE, Seefeld, Germany), applied perpendicular to the surface, at a distance of 10 mm from the surface, for 10 s, under pressure of 2.8 bars;

3. Er:YAG1 group (Er:YAG1): irradiation with 2940 nm Er:YAG laser (Fotona, Fidelis, Ljubljana, Slovenia), applied 1 mm from the surface;

4. Er:YAG4 group (Er:YAG4): irradiation with 2940 nm Er:YAG laser (Fotona, Fidelis, Ljubljana, Slovenia), applied 4 mm from the surface;

5. The Er:YAG7 group (Er:YAG7): irradiation with 2940 nm Er:YAG laser (Fotona, Fidelis, Ljubljana, Slovenia), applied 7 mm from the surface.

The laser parameters settings for all laser treatment groups were 60% water (7 ml/min) and 40 % air for cooling, frequency of 10 Hz, 200 mJ of energy, 600 µs of pulse duration, 20 s of irradiation time and, non contact application mode (R02-C angled handpiece, 0.9-mm spot size). The irradiation was applied parallel to the surface of the block at a constant working distance from the destination, according with each group (1, 4 or 7 mm) measured by a millimeter ruler between the base of the pen and the surface of the Y-TZP. The block was attached to a semiadjustable base, which was moved in the lateral-lateral direction during the irradiation procedure (11). Subsequently the laser irradiation, all blocks were cleaned with an isopropyl ethanol in an ultrasonic vibration (Alpha 3L Plus; Ecel Indústria e Comércio, Ribeirão Preto, SP, Brazil) for 10 min.

Vickers Microhardness

The Vickers microhardness was measured for each group (n = 20) using a digital microhardness tester (HMV-2, Shimadzu Tech. Corp., Kyoto, Japan). Five equidistant Vickers indentations were made in each block with a diamond indenter presenting square-base pyramid-shaped at an 136-degree angle between planes. A load of 0.980 N was applied for 20 seconds. The diagonal length of the observed indentations was measured and the arithmetic mean of Vickers microhardness (HV) value was determined.

Topography and roughness

The surface characteristics of each group (n = 20) were assessed using a confocal laser microscopy (LEXT OLS4000, Olympus, Tokyo, Japan). The test surface of each block was positioned parallel to the surface of the objective and the images were captured with ×50 magnification and 0.2-µm of accuracy. The microscope used was coupled to a program (OLS4000, Olympus, Tokyo, Japan) that allowed the measurement of surface roughness (µm) using the Ra parameter (arithmetical mean of the absolute values of the peaks and valleys measured from a medium plane). Roughness measurements were made in the central area of the block (500 μm^2) being that five equidistant measurements were performed for each block.

X-ray diffractometry

Two blocks of each group were scanned by the X-ray diffractometer (D2 Phaser; Bruker, Karlsruhe, Germany) to analyze the crystalline grain phase arrangement. Spectra were collected with CuKα radiation (1.54060 Å), power of 30 kV, 10 mA current, 2θ scanning range of 10 to 80°, step size of 0.05°, step interval of 0.5 s, sample rotation of 7 rpm, and LynxEye detector.

Micromorphological evaluation by scanning electron microscopy

To qualitatively analyze the microstructure of the Y-TZP surface after the different surface treatments, the surface of each block (n = 2) was observed using a scanning electron microscope (SEM EVO 50, Carl Zeiss, Cambridge, UK). For SEM analyses each block were sputter-coated with an enriched gold alloy (SCD 050, Baltec, Balzers, Liechtenstein) for 120 s and 0.1 mbar vacuum under ×1500, ×5000, ×20,000, and ×50,000 magnifications.

Specimen preparation for bond strength

One hundred Y-TZP blocks (IPS emax ZirCAD; Ivoclar Vivadent, Schaan, Liechtenstein) were embedded in a plastic cylinder (25 mm diameter, 20 mm in height) (Tigre S.A. Participações, Joinville, Santa Catarina, Brazil) with autopolymerized acrylic resin (Clássico Produtos Odontológicos, Campo Limpo Paulista, SP, Brasil). The Y-TZP surface was polished with silicon carbide papers (#600 to #1200 grit size, 3M, St. Paul, MN, USA) in a metallographic polisher (MetaServ 250; Buehler, Lake Bluff, Ill.) until a surface area at least 20 mm^2 was exposed. After that the specimens were immersed in isopropyl ethanol, cleaned by ultrasonic vibration for 10 minutes, and subdivided into two subgroups (n = 10), according to the resin cement used: MDP+ subgroup, self-adhesive resin cement contained 10-MDP (Panavia F2.0; Kuraray Medical, Tokyo), and MDP– subgroup, self-adhesive resin cement without 10-MDP (RelyX U200; 3M/ESPE, St. Paul, MN, USA).

For the specimens of the MDP– subgroup, silane coupling agent (RelyX Ceramic Primer; 3M/ESPE, St. Paul, MN, USA) was applied on the surface of the Y-TZP for 1 min, followed by one layer of adhesive system (Adper Scotchbond Multi-Purpose Plus; 3M/ESPE, St. Paul, MN, USA) that was dried with 5 s air jets, according to the manufacturer's instructions.

Shear bond strength testing of all specimens were created in the centre of the Y-TZP surface using a cylindric bipartite polytetrafluoroethene (Teflon) matrix (3.5 mm diameter and 3 mm length) (25). The

matrix was filled with the cement, light-cured for 20 s using a light-emitting diodes (LED) curing unit with a power density of 1500 mW/cm^2 (Radii Plus; SDI, Bayswater, Victoria, Australia), according to the manufacturer's instructions. The matrix was opened and the specimen was then stored in distilled water at 37^{0}C for 24 h.

Shear bond strength test

The specimens were mounted in a universal testing machine (Biopdi, São Carlos, SP, Brazil), and the load was applied in the Y-TZP-resin cement interface with a 500-kg load cell and at a constant crosshead speed of 0.5 mm/min until failure occurred. The shear bond strength (S) was expressed in MPa and calculated according to the formula S = F/A, where F is the maximum force recorded during the test (in newtons) and A is the adhesive area (9.60 mm^2).

Failure analysis

The adhered surface of each specimen was evaluated with a stereomicroscope (Leica DFC295 attached to Leica S8 APO, Leica Microsystems, Wetzlar, Germany) at ×40 magnification and classified as: adhesive, failure at the Y-TZP–resin cement interface; cohesive, failure in the Y-TZP or in the resin cement; and mixed, failure involved both the Y-TZP and the resin cement.

Data analysis

The Kolmogorov-Smirnov statistical test for normality and the Levéne test for homogeneity revealed a normal distribution for the data ($p > 0.05$). The Vickers microhardness and surface roughness were analyzed by means of one-factor ANOVA and Tukey's complementary test with $\alpha = 0.05$. Two-way ANOVA and Tukey's post-hoc test were used to analyze the bond strength results, with $\alpha = 0.05$. The results were conducted statistically using SPSS software (SPSS 15.0, SPSS Inc., Chicago, IL, USA).

Results

The data (means and standard deviations) for Vickers microhardness before and after surface treatment are presented in Table 2. The statistical analysis revealed no statistically difference significance among the groups ($p > 0.05$). Regarding the roughness, confocal laser microscopy data demonstrated statistically significant difference among the groups (Table 2), being that C+ group had the highest values ($p < 0.05$) and the Er:YAG4 and Er:YAG7 groups presented lowest mean values ($p < 0.05$), which were statistically similar to each other. In the topography analysis, C+ group presented irregular and heterogeneous surface, whereas the other groups (C-, Er:YAG1, Er:YAG4, and Er:YAG7) presented smoother surfaces.

Table 2. Mean (standard deviation, SD) results of the different analyses (Vickers microhardness [HV], roughness [Ra], and shear bond strength [MPa])

Groups	Vickers microhardness (HV)* Mean (±SD)		Roughness Ra (µm)* Mean (±SD)		Bond strength (MPa)* Mean (±SD)	
	Before	After	Before	After	MDP+	MDP-
C-	1345 (±42.2)^{aA}	1345 (±42.2)^{aA}	1.02 (0.2)^{aA}	0.98 (0.1)^{aB}	5.6 (0.9)^{aB}	5.2 (0.8)^{aB}
C+	1344 (±81.3)^{aA}	1346 (±83.3)^{aA}	0.88 (0.1)^{aA}	2.53 (0.1)^{bA}	8.4 (0.9)^{aA}	7.8 (0.9)^{aA}
Er:YAG-1	1395 (±57.7)^{aA}	1394 (±41.8)^{aA}	0.98 (0.1)^{aA}	0.95 (0.3)^{aB}	5.7 (1.3)^{aB}	5.4 (1.1)^{aB}
Er:YAG-4	1344 (±67.0)^{aA}	1348 (±58.6)^{aA}	0.87 (0.1)^{aA}	0.50 (0.1)^{bC}	4.6 (1.2)^{aC}	4.3 (1.1)^{aC}
Er:YAG-7	1347 (±75.8)^{aA}	1348 (±75.3)^{aA}	0.84 (0.2)^{aA}	0.52 (0.9)^{bC}	4.3 (1.1)^{aC}	4.1 (1.1)^{aC}

*Different superscript uppercase letters in columns and lowercase letters in rows indicate statistically significant differences ($p \leq 0.05$).

XRD data indicated that the C- group were composed mainly of tetragonal crystals, whereas in the other groups (C+, Er:YAG1, Er:YAG4, and Er:YAG7) monoclinic peaks were detected. In addition, in the C+ group, silicon dioxide was detected (Figure 1). The SEM images showed lowest surface irregularity for C- group and Er:YAG7 group compared to the other groups, whereas the C+ group presented a rougher surface. The groups irradiated with the Er:YAG laser (Er:YAG1 and Er:YAG4) showed similar surface topography, and were less rough than C+ group (Figure 2).

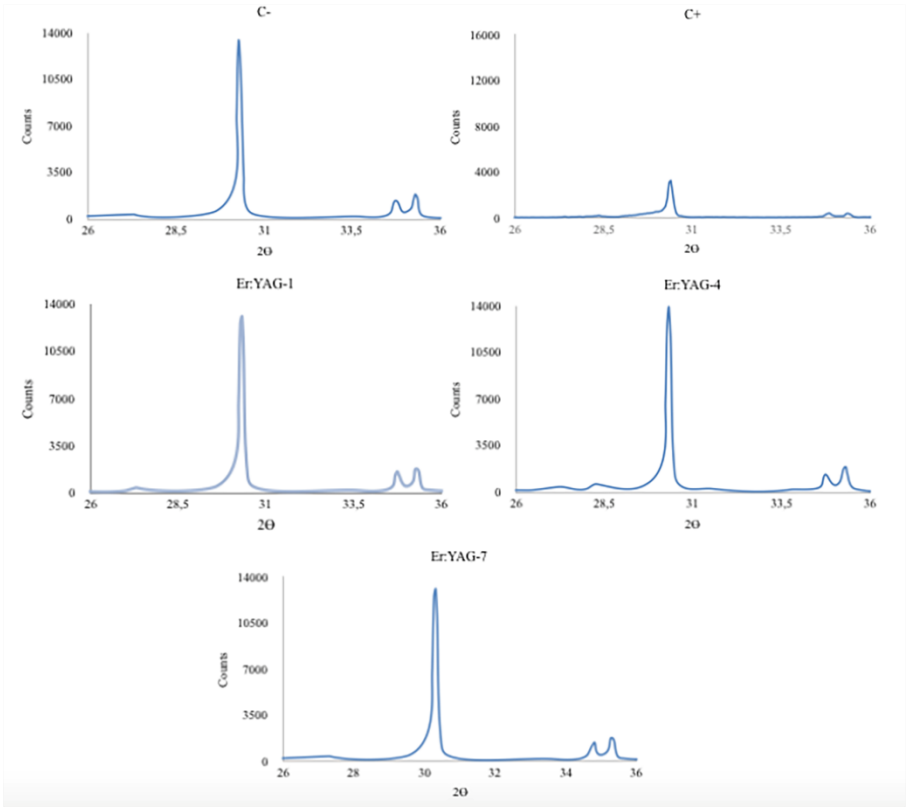

Figure 1. XRD spectra of Y-TZP materials after treatments surface in each experimental group. Higher curve is showing the detected peak for each group.

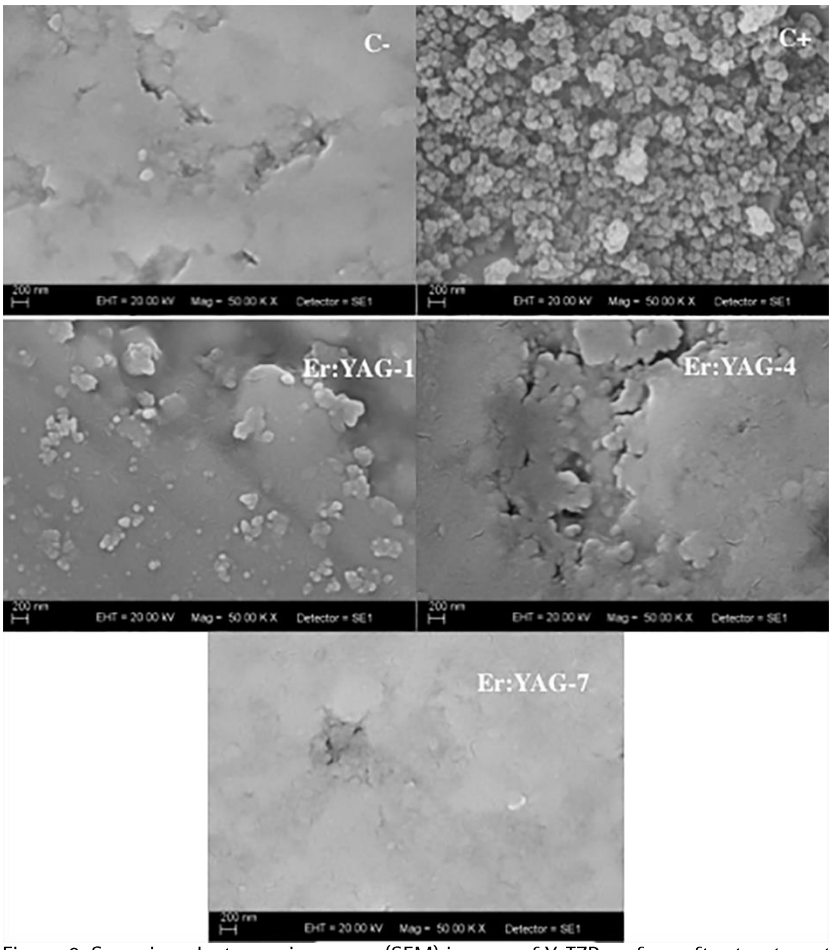

Figure 2. Scanning electron microscopy (SEM) images of Y-TZP surface after treatments surface in each experimental group

The two-factor ANOVA revealed a statistically significant difference in bond strength between the superface treatments ($p < 0.05$). However, there was no difference in relation to the cements studied and in the interaction between the surface treatments and cement (with or without MDP) ($p > 0.05$). The C+ group demonstrated higher shear bond strength than the other groups ($p < 0.05$), whereas the Er:YAG4 and Er:YAG7 groups showed the lowest mean values ($p < 0.05$) which were similar to each other ($p > 0.05$) (Table 2). Failure analysis revealed a predominance of mixed and adhesive failures for all groups (Figure 3).

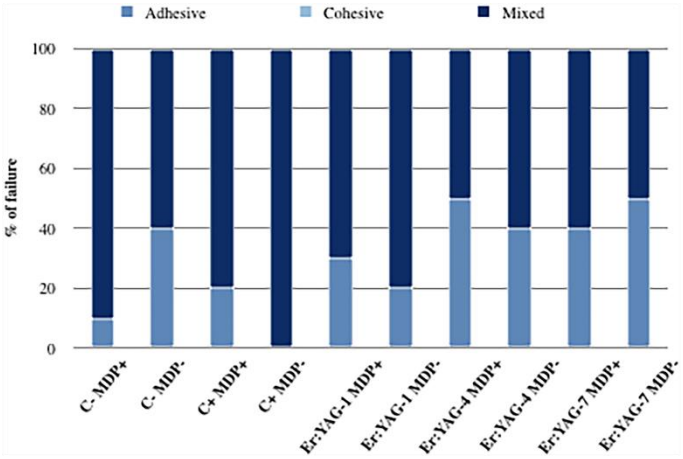

Figure 3. Failure patterns observed in each experimental group

Discussion

In this study, the first null hypotheses for roughness surface and XRD were rejected, but that for Vickers microhardness was accepted. The structural reliability of dental ceramics is associated to the success of full-contour monolithic restorations. In this way, the hardness of the material provide important information about to the clinical applicability, once it is directly related to the resistance of the material to plastic deformation (26). In this study, the Y-TZP Vickers microhardness, determined by the ability of the indenter to penetrate its surface (26), was not affected by the different surface treatments being considered a positive factor.

The sandblasting with silica-coated aluminum oxide particles show improvement in the surface roughness of Y-TZP because these particles help to clean the surface of the material and the silica deposition cause changes in its topography creating irregularities. Such changes result in increased surface energy and wettability and thereby increase the adhesive potential (26). In this study, surface treatment in the positive control group, with silica-coated aluminum oxide particles, significantly increased the surface roughness of Y-TZP, as in previous studies (19,27).

The actual effect of laser energy on the surface of the material is provided by the conversion of light energy into heat, and the amount of water the material contains can affect the energy absorbed (28). In addition, several parameters previously established for the laser irradiation can also directly interfere with the surface characteristics of the Y-TZP. Different energy intensities of the Er:YAG laser were compared in many studies to determine reliable parameters for Y-TZP (20,29). So, in this study it was selected the parameters (energy level of 200 mJ, frequency of 10 Hz, and pulse duration of 600 µs) that produced better adhesion quality between Y-TZP and cement observed in previous study (20,29). On the other hand, there is no consensus to the best parameters to be used in relation to the focal distance between the Er:YAG laser and the surface of the Y-TZP. It is important to avoid the generation of excessive heat on the surface treated (30), because the zirconia is sensitive to the temperature variation and can undergo transformation from the stable tetragonal phase to the monoclinic phase.

The surface roughness for Er:YAG1 group was similar to the negative control group, which was not submitted any surface treatment (27,31), while the Er:YAG4 and Er:YAG7 groups showed lowest values compared to them. Laser energy is known to affect dental hard tissues by ablation, which is the result of microexplosions of water molecules present in the crystalline and organic components of dentin; surface pigmentation and water content are factors determining the energy absorbed by the irradiated area (32). However, because Y-TZP contains no water molecules and has opaque coloration, the effect of the laser on this substrate is not yet clear. The increase in the focal distance from the laser to the substrate may have generated greater diffraction of the laser light and, consequently, a lower energy density, which can be negatively influenced the laser absorption by the reflective surface of the Y-TZP in this study (33).

In the selection of surface treatment for Y-TZP, it is necessary to remember that this procedure can induce the toughening mechanism which is based on tetragonal [t] to monoclinic [m] phase transformations that results in exposition of the grains in the Y-TZP surface, increase of the surface roughness, and better adhesion to the substrate. On the other hand, the same t-m phase transformation mechanism can lead to the microcracks at the surface, weakening and reducing the bond strength of Y-TZP. This clinical situation would imply the early fracture of the dental reabilitation (34). In this study, the surface treatments led to the phase transformation (t-m) of zirconia at different levels between groups treated to the Er:YAG laser. The monoclinic phase was presented in all groups submitted to surface treatment. In relation to surface sandblasting, it is believed that the t-m phase transformation was caused by the increase in the volume of the crystals as a result of a superficial compressive layer criated by silica deposition (6). With regard to the lasers groups, it is suggested that the thermal effect generated during irradiation, even with the water spray used during the procedure, was not sufficient to avoid the t-m phase transformation (35).

The second null hypothesis was rejected because the bond strength was affected by the surface treatments but not for the resin cements. Such a result can be explained by the fact that the MDP present in Panavia F2.0 resin cement has the ability to establish connections with metal oxides present on the Y-TZP surface and provide van der Waals forces or hydrogen bonds at the Y-TZP–resin cement interface (36,37). On the other hand, RelyX U200 contains groups of phosphoric acid or adhesive functional monomers capable of reacting chemically with oxides (5) and hydroxyl groups (38) on the zirconia surface.

The superiority of surface sandblasting with silica-coated aluminum oxide (positive control group) was verified in the bond strength between Y-TZP and resin cement, in relation to the other groups. It is believed that the silica layer created on the surface of the Y-TZP can reacts with the RelyX U200 silane and the MDP in Panavia F2.0, which can be considered a chemically strong and hydrolytically stable bond (7); in addition, the increase in surface roughness provided the best results of bond strength in relation to the other surface treatments studied. In this way, the sandblasting surface provides a more intimate contact between the cement and the Y-TZP, reducing the interfacial faults and presenting favorable failure pattern results, as observed in the results of this study; where, the negative control, positive control, and Er:YAG1 groups showed higher percentages of mixed-type failures, whereas the Er:YAG4 and Er:YAG7 groups each had similar percentages of mixed and adhesive failures. Mixed-type failures are clinically preferred to adhesive failures because in mixed failure, interfacial bonding is usually adequate (39). The absence of cohesive failure suggests that surface treatments, especially the use of the Er:YAG laser, did not induce the internal weakening of Y-TZP (8,10,20).

The bonding strength in the Er:YAG1 group was similar to that of the negative control group, which was not subjected to surface treatment, and Er:YAG4 and Er:YAG7 groups had the poorest bond strength. The results suggesting that the change in the focal distance, purposed in this study, did not increase the surface roughess, resulting in a less efficient bond strength than sandblasting with silica-coated aluminum oxide particles. The analyses of the surface topography by confocal laser microscopy and SEM, and the surface roughness values of this study were similiar from the results showed for some previous studies (40,41). Clinically, the results obtained in this study is important, once the focal distance did not show a significant change in the t-m phase in the Y-TZP surface which show the presenvation of resistance and clinical durability of the material. But, it is important to highlight that this study has some limitations, once did not evaluated other parameters during the application of the Er:YAG laser, such as frequency, cooling, pulse duration, time application, and energy. Furthermore, some differences in bond strength could be due to different cyclic loading or thermocycling protocols. Maybe this points should be study to define the most favorable parameters to garantee the bonding strength without surface caracteristics changes.

Conclusions

This study has found that the sandblasting with silica-coated aluminum oxide particles provide better surface characteristics (topography and roughness, micromorphology, and phase transformation) and bond strength of the Y-TZP, compared with Er:YAG laser treatment, regardless of focal distance; the presence of MDP in the composition of resin cement had no influence on the bond strength of Y-TZP.

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Resumo

Este estudo avaliou as características de superfície e resistência de união de Y-TZP tratado com laser de Er: YAG em diferentes distâncias focais. Cento e vinte blocos de Y-TZP foram divididos em cinco grupos (n=24), de acordo com a superfície de tratamento: sem tratamento (C-); asperização com partículas de óxido de alumínio revestidas por sílica (C +); e aplicação de laser Er: YAG a distâncias focais de 1 mm (Er: YAG-1), 4 mm (Er: YAG-4) e 7 mm (Er: YAG-7). As características de superfície foram analisadas por meio de microdureza Vickers, microscópio confocal a laser, microscopia eletrônica de varredura (MEV) e difratômetro de raios-X (DRX). Para o ensaio de resistência de união, cem blocos de Y-TZP foram subdivididos em 2 subgrupos (n=10) de acordo com o cimento resinoso utilizado (n=12): com 10-metacriloiloxidecil dihidrogenofosfato (MDP+) ou sem (MDP-). Microdureza Vickers e rugosidade de superfície foram analisadas por ANOVA a 1 fator e a resistência de união por ANOVA a 2 fatores e ambos seguidos de teste complementar de Tukey (α=0,05). Não foram observadas diferenças de microdureza Vickers entre os grupos; C+ apresentou maiores valores de rugosidade superficial. Imagens de MEV mostraram diferenças micromorfológicas entre os grupos. Os dados de DRX detectaram apenas cristais tetragonais para C- e, para os outros grupos, picos de zircônia nas fases tetragonal e monoclínica. Para a resistência de união, não foram observadas diferenças estatisticamente significante entre os cimentos com e sem MDP ($p>0.05$), mas foram observadas diferenças significativas entre os tratamentos de superfície (C+ > C- = Er:YAG1 > Er:YAG4 = Er:YAG7) ($p<0.05$). Sugere-se que o laser de Er: YAG não pode substituir o tratamento convencional com partículas de óxido de alumínio e a presença de MDP no cimento resinoso não influenciou na resistência de união.

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