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ORIGINAL ARTICLE

Surface alterations of zirconia and titanium substrates after Er,Cr:YSGG irradiation

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Abstract This study investigated changes in the roughness parameters (Sa in μm^2 and Ra in μm) of yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP) and large-grit sandblasted acid-etched (SLA) titanium (TI) materials after decontamination by erbium chromium-doped:yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser irradiation. Twenty disks were analyzed in this study: 10 disks of Y-TZP (5 mm in diameter and 3 mm in height), standardized with CAD–CAM procedures, and 10 disks of SLA TI (5 mm in diameter and 4 mm in thickness). Disks were randomized into four groups (n=5), according to whether laser irradiation was performed: Y-TZP_G1 and TI_G1 were not treated by laser (control groups), whereas Y-TZP_G2 and TI_G2 were irradiated with Er,Cr:YSGG laser (1.5 W/20 Hz, air–water cooling proportion of 80 %/25 %). The surface topography of the disks was analyzed by confocal light microscopy. The mean Sa and Ra values were calculated from five profiles from each group. The results were statistically analyzed by *t*-test at the 95 % confidence level (α=0.05). For Y-TZP, the Sa results (in mean±SD) for Y-TZP_G1 and Y-TZP_G2 were 2.60±1.1 and 0.80±0.17 μm^2, respectively, and the Ra results were 2.01±0.71 and 0.18±0.15 μm, respectively (both $p<.05$). For SLA TI, the Sa results for TI_G1 and TI_G2 were 1.99±0.5 and 3.37±0.75 μm^2, respectively, and the Ra results were 1.78±0.53 and 3.84±0.63 μm, respectively (both $p<.05$). Er,Cr:YSGG laser irradiation alters the surface roughness of zirconia and SLA TI.

Keywords Laser · Zirconia · Titanium

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The rehabilitation of partially or totally edentulous patients with titanium (TI) implants has been associated with high success rates [1, 2]. The topography of the implant surface is a relevant factor for obtaining osseointegration [3, 4]. As-machined surfaces are relatively smoother than nano- and microstructured surfaces, and rougher surfaces show an increase in the bone-to-implant contact (BIC) that favors osseointegration [4]. Large-grit sandblasting with acid etching (SLA) is an implant surface modification that can improve osseointegration [5, 6]. Surface properties such as roughness also have a strong correlation with cellular behaviors, including adhesion, functional alterations, and proliferation [5].

Progress has been made in fabricating abutments and dental implant surfaces from zirconia ceramics [7, 8]. Pure zirconia can assume three crystallographic forms: monoclinic, tetragonal, and cubic [9]. Zirconia is the common name for zirconium dioxide (ZrO_2) [10]. The addition of stabilizing oxides, such as Y_2O_3, allows the tetragonal structure to be retained at room temperature [9]. Zirconia ceramics, including yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP), feature biocompatibility, a tooth-like color, and inherent strength [11–13]. Y-TZP has been used as an alternative to TI for abutments and as a dental implant material [14–16]. The zirconia surface may also demonstrate decreased bacterial adhesion [17].

Studies raised some concerns regarding peri-implant disease [18, 19], which is caused by periodontal pathogens that

Table 1 Effects of Er,Cr:YSGG laser irradiation for Y-TZP material on roughness parameters (Sa). Means [standard deviations] of Sa roughness parameters (μm^2) and the results of Tukey's test for factor laser for Y-TZP material

Parameter/treatment Y-TZP	n	Mean [standard deviation]	Maximum value	Minimum value
Sa (μm^2)				
Control (Y-TZP_G1)	5	2.60 [1.1] A	5.988	35.826
1.5 W/20 Hz/30 s–(air/water) 80 %/25 % (Y-TZP_G2)	5	0.81 [0.17] B	3.009	3.197

Means followed by different upper case letters at column indicate statistical differences ($p<0.05$). n=sample number

Table 2 Effects of Er,Cr:YSGG laser irradiation for Y-TZP material on roughness parameters (Ra). Means [standard deviations] of Ra roughness parameters (μm) and the results of Tukey's test for factor laser for Y-TZP material

Parameter/treatment Y-TZP	n	Mean [standard deviation]	Maximum value	Minimum value
Ra (μm)				
Control (Y-TZP_G1)	5	2.01 [0.71] A	4.946	30.818
1.5 W/20 Hz/30 s–(air/water) 80 %/25 % (Y-TZP_G2)	5	0.18 [0.15] B	0.472	1.236

Means followed by different upper case letters at column indicate statistical differences ($p<0.05$). n=sample number

incite bleeding on probing and crestal bone resorption [5, 19]. The implant surface can be decontaminated by several methods, such as ultrasonic and air–powder systems, as well as curette treatment [20–24]. Several laser systems have been studied for this purpose [25], including the gallium aluminum arsenide (GaAlAs) diode laser (980 nm in wavelength) [24–28], the neodymium-doped yttrium aluminum garnet (Nd:YAG) laser (1064 nm) [27, 29], the erbium (Er):YAG laser (2940 nm) [13, 22, 23, 26, 30, 31], the carbon dioxide laser [12, 20, 24, 26, 28, 30], and the erbium chromium-doped:yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser (2780 nm) [32–34].

Er,Cr:YSGG laser irradiation (at 1.5 W with water irrigation) has been studied as an alternative tool to decontaminate the surface of titanium implants presenting osteoblast attachment [32, 34, 35]. Although increased surface roughness may improve the bone healing response, it can also increase dental biofilm accumulation. This biofilm can be effectively removed by Er,Cr:YSGG laser irradiation [35]. Heat conduction is minimized by using a water spray for cooling, to avoid thermal effects such as cracks and melted areas. However, disagreement remains as to whether direct laser application causes changes to the TI surface [36]. The aim of the study was to investigate the effects of Er,Cr:YSGG laser irradiation under different conditions on roughness parameters for Y-TZP and SLA TI materials.

Results

Tables 1, 2, 3, and 4 report the effects of Er,Cr:YSGG laser irradiation on the roughness parameters (Sa and Ra) of the Y-TZP material (Tables 1 and 2) and the SLA TI material (Tables 3 and 4). For Y-TZP, the untreated (control) group had higher Sa and Ra values than the laser-treated groups ($p<.05$ by *t*-test). The mean Sa values for Y-TZP_G1 and Y-TZP_G2 were 2.60 and 0.80 μm^2, respectively (Table 1). For SLA TI, the untreated control group had lower Sa and Ra values than the laser-treated group ($p<.05$ by *t*-test). The mean Sa values for TI_G1 and TI_G2 were 1.99 and 3.37 μm^2, respectively (Table 3).

Table 3 Effects of Er,Cr:YSGG laser irradiation for titanium SLA material on roughness parameters (Sa). Means [standard deviations] of Sa roughness parameters (μm^2) and the results of paired *t*-test for titanium material

Parameter/treatment titanium SLA	n	Mean [standard deviation]	Maximum value	Minimum value
Sa (μm^2)				
Control (TI_G1)	5	1.99 [0.50] B	4.148	32.047
1.5 W/20 Hz/30 s–(air/water) 80 %/25 % (TI_G2)	5	3.37 [0.75] A	11.468	12.584

Means followed by different upper case letters at column indicate statistical differences ($p<0.05$). n=sample number

Table 4 Effects of Er,Cr:YSGG laser irradiation for titanium SLA material on roughness parameters (Ra). Means [standard deviations] of Ra roughness parameters (μm) and the results of paired *t*-test test for titanium material

Parameter/treatment titanium SLA	n	Mean [standard deviation]	Maximum value	Minimum value
Ra (μm)				
Control (TI_G1)	5	1.78 [0.53] B	3.379	26.911
1.5 W/20 Hz/30 s–(air/water) 80 %/25 % (TI_G2)	5	3.84 [0.63] A	12.505	7.308

Means followed by different upper case letters at column indicate statistical differences ($p<0.05$). n=sample number

Figures 1 and 2 show representative images obtained for the Y-TZP_G1 and Y-TZP_G2 groups, respectively. Figures 3 and 4 show the representative images obtained for TI_G1 and TI_G2, respectively. For the irradiated groups, the disks were treated with Er,Cr:YSGG (air/water 80 %/25 %). In addition to projections, the irradiated titanium surface (TI_G2) showed cracks with projections of 8 μm in height.

Discussion

Progression of a peri-implant infection can cause dental implant loss [19]. Plaque biofilm can alter the surface characteristics of the TI implant. Bacterial contamination of the surface has been shown to increase the amount of carbon at the dioxide layer [5, 35, 37]. The implant surface can be decontaminated by using chemical and mechanical agents, permitting subsequent re-osseointegration of the previously contaminated implant surface [38].

Studies have described thermal alterations of SLA-treated TI, such as melting after Er,Cr:YSGG laser irradiation, due to energy transfer to the TI surface. These changes are associated with the development of surface color changes and morphological damage [39]. Using scanning electron microscopy, Stubinger et al. [26] observed melted areas of the SLA-treated TI surface that had been irradiated by Er:YAG.

Sites with peri-implantitis can exhibit bacterial biofilm that is similar to chronic periodontitis [18, 35], which must be removed. Er,Cr:YSGG laser irradiation can be used to decontaminate the surface of the TI implant [34, 35]. In the present study, a power output setting of 1.5 W was selected on the basis of osteoblast attachment, according to studies by Romanos et al. [34] and Schwarz et al. [35]. On the other hand, a recent study [40] indicated that the use of an Er:YAG laser at 200 mJ/10 Hz can alter the TI implant surface with a negative effect on the viability and activity of osteoblasts. Figure 4 presents the irradiated TI surface. When the temperature surpasses the metallic melting and boiling thresholds, boiling occurs [39]. Changes (e.g., melting, coagulation, and exfoliation) of the coated implant surface after laser irradiation may have a negative effect on the BIC and affect the success of implant treatment [36, 39].

TI has been demonstrated to interact with laser treatment in different ways depending on the surface. In a previous report, the interaction of Er,Cr:YSGG with TI plasma-sprayed showed no superficial alteration under the highest power setting (6 W) [33]. However, our study showed superficial alterations at a lower power setting (1.5 W) and significant differences compared to the control group, with an increase in

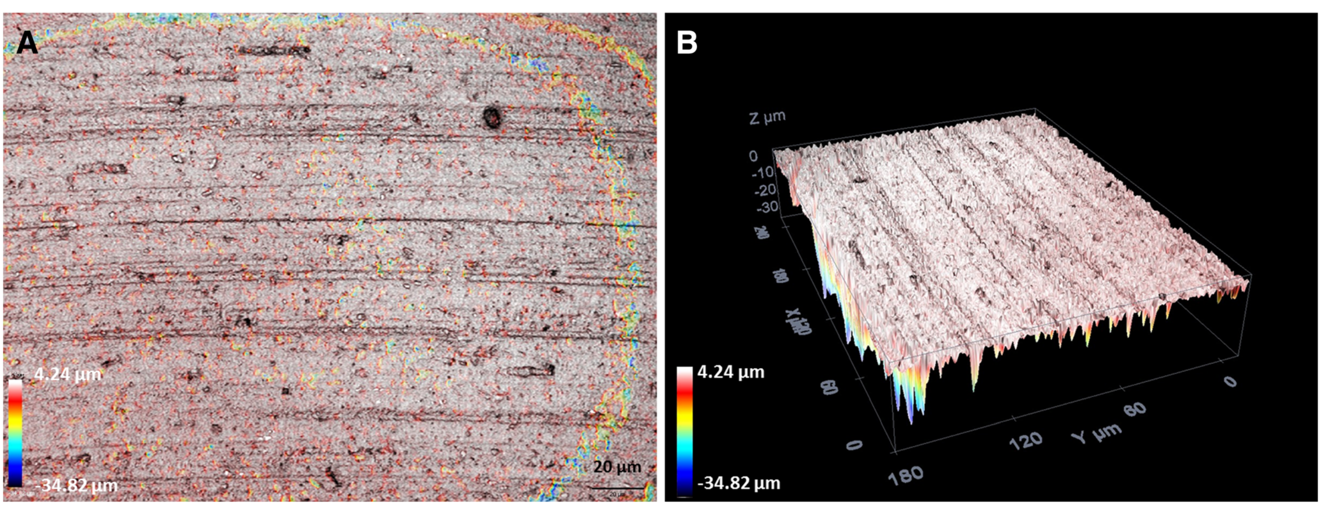

Fig. 1 **A** Representative 2D image obtained for Y-TZP zirconia material (Y-TZP_G1: control group) (50×). **B** Representative 3D image obtained for Y-TZP zirconia material (Y-TZP_G1: control group) (bar: 20 μm) (50×)

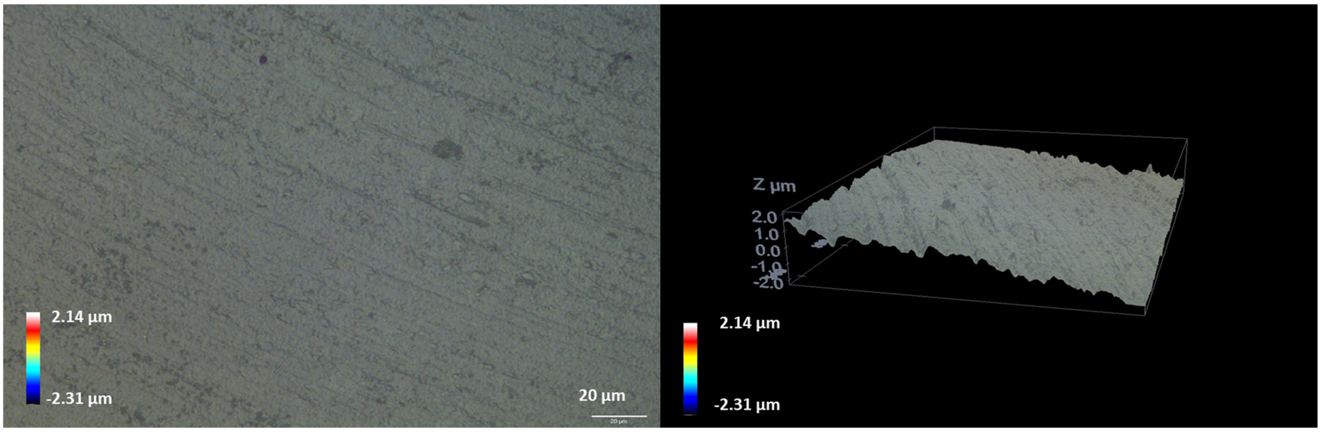

Fig. 2 **A** Representative 2D image obtained for irradiated Y-TZP zirconia material (Y-TZP_G2: Er,Cr:YSGG). **B** Representative 3D image obtained for irradiated Y-TZP zirconia material (Y-TZP_G2: Er,Cr:YSGG) (bar: 20 μm) (50×)

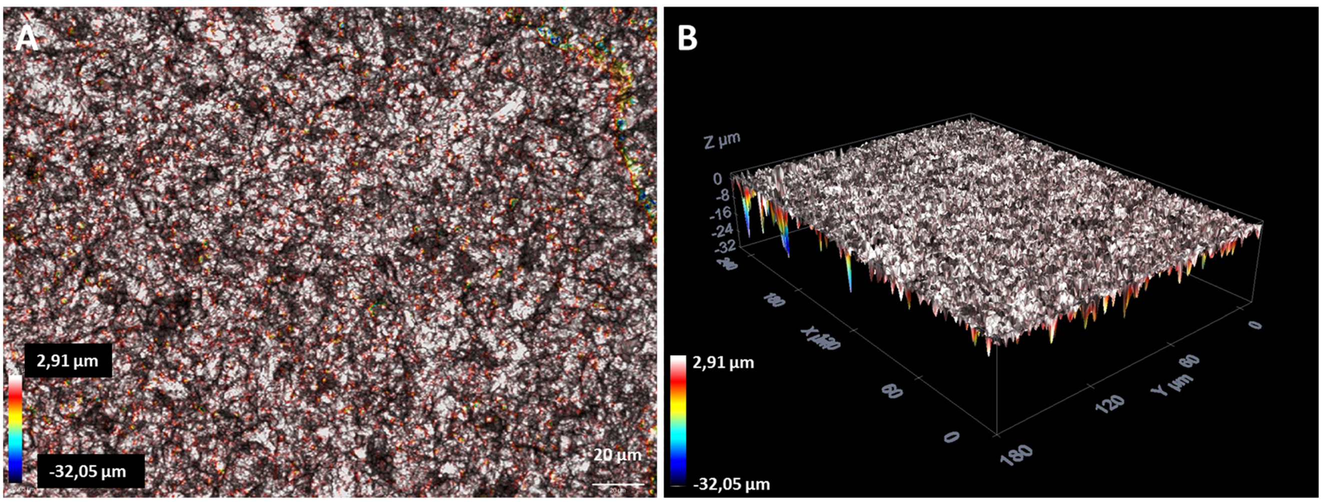

Fig. 3 **A** Representative 2D image obtained for titanium SLA material (TI_G1: control group) (50×). **B** Representative 3D image obtained for titanium SLA material (TI_G1: control group) (bar: 20 μm) (50×)

roughness and the presence of cracks. The TI surface presented visual alterations, which were confirmed by the confocal microscopy images. Parameters such as the output power, irradiation dose and duration, and the distance between the laser tip and the irradiated surface should also be considered [36].

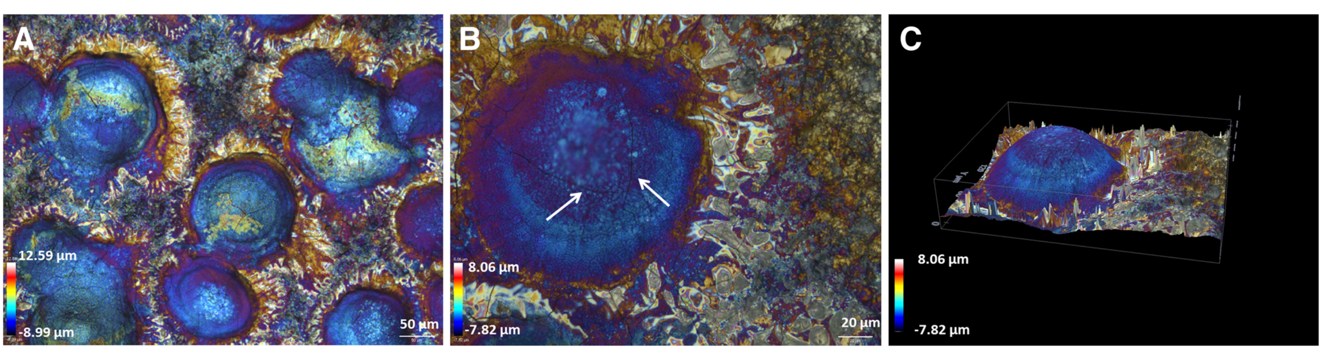

Fig. 4 **A** Representative 2D image obtained for irradiated titanium material (TI_G2: Er,Cr:YSGG) (20×). **B** Representative 2D image obtained for irradiated titanium material (TI_G2: Er,Cr:YSGG) (50×). There is evidence of thermal damage with projection and cracks on surface (*arrows*). **C** Representative 3D image obtained for irradiated titanium material (TI_G2: Er,Cr:YSGG) (bar: 20 μm) (50×)

Schwarz et al. [35] evaluated the decontamination of the SLA-treated TI surface with Er,Cr:YSGG at 1.5 W/20 Hz with an air/water proportion of 50 %/50 %. Using a methodology that was very similar to that of the present study, the authors related no thermal effect, such as melting or loss of porosity. The laser was applied in contact mode, whereas the present study used the focused mode. This fact could explain the morphological alterations and increased roughness found in this study.

The clinical application of the Er,Cr:YSGG laser to decontaminate the implant surface is different from the in vitro situation, given the presence of water in the oral cavity from the gingival fluid, saliva, and blood. The wavelength of the Er,Cr:YSGG laser is highly specific to water, and the utility of laser treatment for decontaminating superficial implants can be different in clinical situations. Moreover, the present paper describes the topography of disks and not real implants, so the relevance is limited. The good clinical results presented by Azzeh et al. [32] corroborate these results, although the surface topography of irradiated TI was not reported.

Zirconia material is widely used in biomedicine due its good properties [14]. It presents lower bacterial adhesion and biofilm formation compared to other currently used dental materials [17]. Using scanning electron microscopy, Stubinger et al. [12] analyzed the Er:YAG-irradiated zirconia surface under several settings and found no superficial alteration. Our results disagree with these findings because the Y-TZP disks showed decreased roughness and concomitant 3D alterations (Fig. 3B). When the implant surface characteristics are altered due to the use of inappropriate laser settings, the reattachment of connective tissue to the implant surface can be affected. Therefore, the surface morphology should not be modified during the decontamination process [36, 39].

To the best of our knowledge, there are no comparable studies. Therefore, further analysis is needed, especially of osteoblast behavior on laser-modified surfaces and the clinical use of this technique.

Conclusion

- The Er,Cr:YSGG-irradiated Y-TZP surface showed a decrease in surface roughness compared to the non-irradiated group.
- In contrast, the irradiated SLA TI surface showed an increase in surface roughness compared to the non-irradiated group, with the presence of superficial cracks.
- Er,Cr:YSGG laser irradiation alters the surface roughness of zirconia and SLA TI.

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