Research Article

Effect of erbium-doped: yttrium, aluminium and garnet laser irradiation on the surface microstructure and roughness of sand-blasted, large grit, acid-etched implants

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Purpose: The present study was performed to evaluate the effect of erbium-doped: yttrium, aluminium and garnet (Er:YAG) laser irradiation on sand-blasted, large grit, acid-etched (SLA) implant surface microstructure according to varying energy levels and application times of the laser.
Methods: The implant surface was irradiated by the Er:YAG laser under combined conditions of 100, 140, or 180 mJ/pulse and an application time of 1 minute, 1.5 minutes, or 2 minutes. Scanning electron microscopy (SEM) was used to examine the surface roughness of the specimens.
Results: All experimental conditions of Er:YAG laser irradiation, except the power setting of 100 mJ/pulse for 1 minute and 1.5 minutes, led to an alteration in the implant surface. SEM evaluation showed a decrease in the surface roughness of the implants. However, the difference was not statistically significant. Alterations of implant surfaces included meltdown and flattening. More extensive alterations were present with increasing laser energy and application time.
Conclusions: To ensure no damage to their surfaces, it is recommended that SLA implants be irradiated with an Er:YAG laser below 100 mJ/pulse and 1.5 minutes for detoxifying the implant surfaces.

Keywords: Dental implants, Lasers.

INTRODUCTION

Dental implants have significantly contributed to recovery of masticatory ability and improved aesthetics for patients with partial or complete tooth loss, effectively replacing conventional dental prostheses over the past decades. Patient satisfaction and treatment prognosis have also substantially improved. However, as better results and a higher success rate have been reported annually, implant-related complications are increasing accordingly.

Complications related to dental implants are attributed to improper implant designs, poor initial stability, and inappropriate osseous tissue conditions. Peri-implantitis is apt to occur in heavy smokers; patients with poor oral hygiene; and those with a history of radioactive therapy, periodontal diseases, and other infections [1-3]. Among these factors, dental implant failure is mainly associated with microorganisms on the surface of implants [4]. Microorganisms cause inflammation in the mucosa around implants, which, if not treated, could spread to the implants' apex and induce bone resorp-

tion, resulting in peri-implantitis [5]. Peri-implantitis related bacteria including *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Fusobacterium spp.*, are also major causes of chronic periodontitis [6]. Mombelli [7] suggested that bactericidal treatment such as detoxifying the implant surface, reducing or removing periodontal pockets, restoring bone tissues and re-osseointegration, and reinforcing oral hygiene should be considered for treating bacteria-contaminated implants. Merffert et al. [8] claimed that exposed implants due to peri-implantitis can be contaminated by bacteria and endotoxin and that biological recovery is not possible without endotoxin eradication. Zablotsky et al. [9] stated that in order to achieve re-osseointegration, sterilization and detoxification of endotoxin-contaminated implant surfaces should be conducted.

Methods to detoxify implant surfaces are divided into three categories: mechanical detoxification using a plastic curet, ultrasonic scaler or air-powder abrasives [9]; chemical detoxification using citric acid, chlorhexidine, tetracycline, hydrogen peroxide, or stannous fluoride [9,10]; and laser-based treatments [11]. Mechanical and chemical methods can cause implant surface changes, and cannot effectively detoxify the surfaces [12-16]. In contrast, laser-based methods are highly effective in sterilization and detoxification, while reducing bleeding, swelling, and pain. Due to these advantages, various laser methods have been suggested for detoxification of implant surfaces.

A laser uses a mechanism of light amplification, emitting electromagnetic radiation via the process of stimulated emission. Currently, carbon dioxide, diode, neodymium-doped: yttrium, aluminum, and garnet (Nd:YAG), and erbium-doped: YAG (Er:YAG) lasers are used in dentistry. Carbon dioxide lasers have sterilizing effects [17] but can cause damage to implant surfaces by carbonization and melting due to temperature increases at intensities over 2 watts [17,18]. Some studies have shown that diode lasers do not cause any changes in implant surfaces [19] but have limited sterilizing effects [20] and cause temperatures to rise to over 47°C [21]. Nd:YAG lasers are known to have little sterilizing effect and cause changes in implant surfaces such as meltdown and microfractures, even at very low laser intensities [19,22]. On the other hand, Er:YAG lasers have shown strong sterilizing effects when irradiating surfaces contaminated with *Streptococcus sanguine* [23]. The lasers were also highly effective in removing endotoxin and inducing osteoblast attachment when applied to implant surfaces contaminated with *P. gingivalis* [24]. It is reported that Er:YAG lasers can be effectively used without causing damage around treated areas [25,26]. In some clinical studies, non-surgical periodontal treatments using Er:YAG lasers significantly reduced probing depth and increased the clinical attachment level [27-29]. In addition, it was found that adhesion of osteoblast-like cells did not decrease even when the laser was applied to titanium discs with an intensity of 12.7 J/cm², and the biocompatibility of the titanium surfaces was not affected [30].

An Er:YAG laser can be effective in treating peri-implantitis. However, Kreisler et al. [11] suggested that proper energy levels for various implant surfaces should be identified because laser irradiation can cause changes in implant surfaces at certain power levels depending on the type of implant surface: titanium plasma spray (TPS) (8.9 J/cm²), sand-blasted, large grit, acid-etched (SLA) (11.2 J/cm²), hydroxyapatite (HA) (17.8 J/cm²), and machined surfaces (28 J/cm²). However, no substantial research has been performed or guidelines developed on the proper power and application time for effective sterilization without modifying implant surfaces. This study was conducted to evaluate the effects of Er:YAG laser irradiation on the roughness and microstructure of SLA implant surfaces according to the power level and application time of the laser, and suggest a proper laser irradiation dose for detoxifying an SLA implant surface without causing significant damage.

MATERIALS AND METHODS

Materials

In this study, a total of ten SLA implants (Xive, Friadent GmbH, Mannheim, Germany), 5.5 mm in diameter and 15 mm in length, were used. Nine implants were used for the laser irradiation test groups and one for the control group.

Test equipment

The implant surfaces were irradiated by Er:YAG laser (KEY3, KaVo Dental GmbH, Biberach, German). Roughness of the surfaces was evaluated by a mechanical contact profilometer (Form Talysurf Laser 635, Taylor Hobson, Leicester, UK) and the microstructure of the surfaces was observed by a scanning electron microscope (S-2300, Hitachi Co., Tokyo, Japan).

Methods

Measuring implant surface roughness

To conduct laser detoxification and measure surface roughness, implant containers were made with dental impression material and putty for stabilization. Areas on the implant surfaces subjected to the test were marked with an oil-based pen, and surface roughness values were measured at three points (2nd, 6th, and 10th valley) of the implant with a mechanical contact profilometer. Average roughness (Ra) was measured with the profilometer at three points on the implants before and after the experiment with a diamond stylus

of radius 5 μm and a stylus angle of 90°. The lower the Ra value, the smoother the surface.

Control and test groups

The implants belonging to the test groups were numbered from one through nine (No. 1 to 9), and the control implant was labeled No. 10. Each test group was then classified into one of three subgroups: group 1 included implant No. 1 to 3, group 2 included No. 4 to 6, and group 3 included No. 7 to 9.

Laser irradiation

The control, No. 10, was the only implant without laser irradiation. Each of the three test groups was irradiated with a different energy level. The implants in group 1 were irradiated with 100 mJ/pulse for 1, 1.5, and 2 minutes each, while the implants of group 2 and 3 were irradiated with 140 mJ/pulse and 180 mJ/pulse, respectively, with the same application times as group 1. The laser was applied to three points (the 2nd, 6th, and 10th valley) of the implants, and each irradiated surface area was 2×2 mm². All the irradiation was conducted with a 2061 handpiece (KaVo Dental GmbH) and truncated cone tip optic fiber with maximum irrigation. The frequency was fixed at 10 Hz and the laser was operated in the near-contact mode. In this mode, the tip of the handpiece was at a distance of 0.5 mm from the implant surfaces and the optical fiber was perpendicular to the surface of the subject in order to maximize the effects. The laser was applied in an up-down and right-left motion for the fixed periods of time. After irradiation, the specimens were dried with air syringes.

SEM observation

The dried surfaces of the specimens were sprayed with gold using an ion sputtering coater before they were examined and photographed by a scanning electron microscope under a magnifying power of 500× and 2,000×. Each of the pictures was evaluated and analyzed to determine any changes in the implant surface structure before and after the laser irradiation.

Statistical analysis

A software package was used for the statistical analysis (SPSS ver. 17.0, SPSS Inc., Chicago, IL, USA). Mean values and standard deviations (SDs) of the implant surface roughness before and after the experiment were calculated and group comparison was performed by a Wilcoxon signed rank sum test. Results were considered to be significant for P-values < 0.05.

RESULTS

Measurement of surface roughness

The mean value $\pm$ SD of surface roughness of the nine SLA implants before laser irradiation was 2.057 ± 0.408 μm. No change was observed in the surface roughness with irradiation at 100 mJ/pulse for 1 minute, while the roughness values decreased with increasing application time to 1.5 and 2 minutes. The roughness values decreased when the test implants were irradiated with 140 mJ/pulse and 180 mJ/pulse, regardless of the application time. However, these changes in the surface roughness before and after the laser irradiation were not statistically significant in all groups (P-value > 0.05) (Table 1).

SEM evaluation

Control group

The SLA implant surface was observed with a scanning electron microscope under 500× and 2,000× magnification. A honeycombed surface structure with very small pits due to corrosion by acid in macroporous valleys was observed (Fig. 1).

Test groups

The implants in group 1 (irradiated at 100 mJ/pulse) showed no changes in the structure of their surfaces after 1 minute and 1.5 minutes of irradiation (Figs. 2, 3). However, as the irradiation time increased to 2 minutes under the same energy intensity, a heat-induced meltdown was observed in the implant surface under microscopic observation at 2,000× (Fig. 4). In group 2 and 3, for which the laser irradiation power increased to 140 mJ/pulse and 180 mJ/pulse, respectively, surface changes were observed in all the implants regardless of the application time. Meltdown and subsequent flattening of the surfaces were observed (Figs. 5B-10B). These changes became more evident with increasing intensity of pulse energy and application time (Figs. 5A-10A).
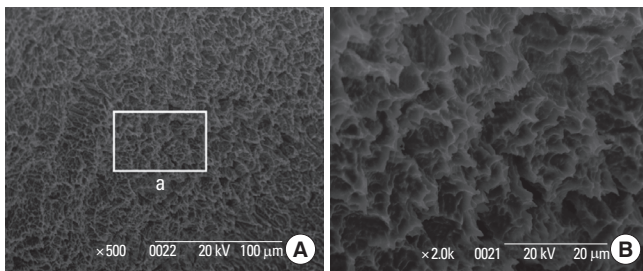
Table 1. Surface roughness values measured 3 valleys (2th, 6th, 10th valley) before & after surface detoxification by laser treatment (mean $\pm$ SD).

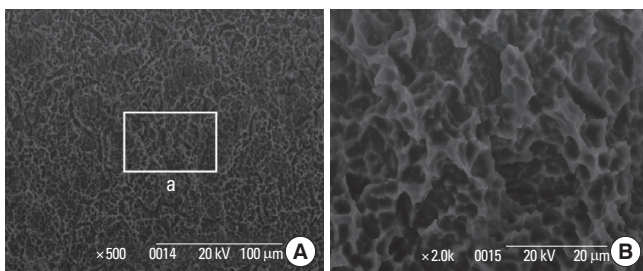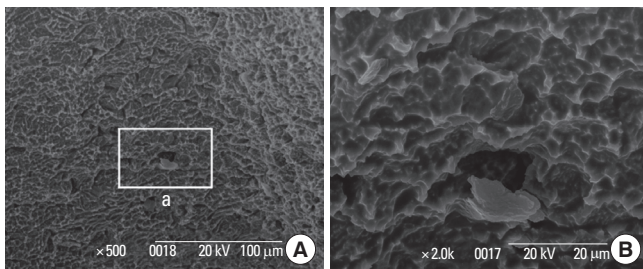| No	Pulse energy (application time, min)	Average roughness value		P-value
		Before laser tx. (n=3, μm)	After laser tx. (n=3, μm)	
1	100 mJ/pulse (1)	1.533±0.796	1.533±0.499	1
2	100 mJ/pulse (1.5)	2.014±0.362	1.665±0.432	0.285
3	100 mJ/pulse (2)	1.856±0.152	1.656±0.453	0.285
4	140 mJ/pulse (1)	2.062±0.158	1.835±0.279	0.285
5	140 mJ/pulse (1.5)	2.169±0.360	2.011±0.317	1
6	140 mJ/pulse (2)	2.187±1.195	1.936±0.908	1
7	180 mJ/pulse (1)	2.085±0.176	1.968±0.163	0.285
8	180 mJ/pulse (1.5)	2.346±0.268	2.008±0.247	0.109
9	180 mJ/pulse (2)	2.260±0.204	2.258±0.155	1

tx.: treatment.
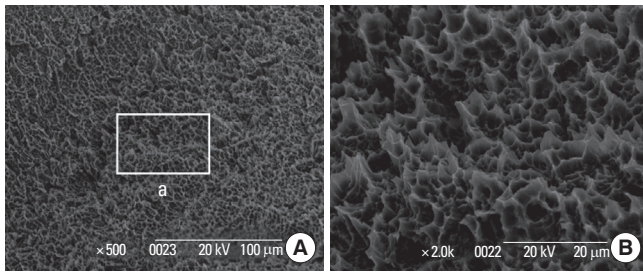
Figure 1. (A) Control specimen. Sand-blasted, large grit, acid-etched implant surface without any conditioning (×500). (B) Inset of Figure 1A. Many macroporous valleys and microrough pits are observed (×2,000).
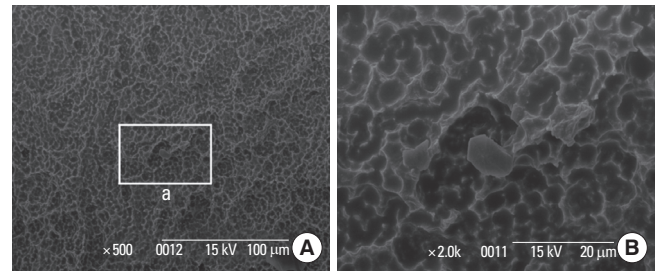

Figure 5. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 140 mJ/pulse for 1 minute (×500). (B) Inset of Figure 5A. Melted surface is observed (×2,000).

Figure 2. (A) Sand-blasted, large grit, acid-etched implant surface irradiatedt 100 mJ/pulse for 1 minute (×500). (B) Inset of Figure 2A. Note no remarkable change (×2,000).

Figure 6. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 140 mJ/pulse for 1.5 minutes (×500). (B) Inset of Figure 6A. Flattened surface is observed (×2,000).

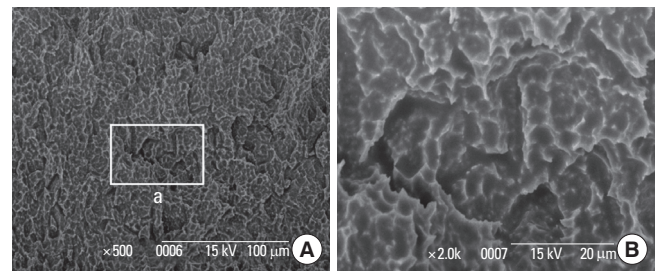

Figure 3. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 100 mJ/pulse for 1.5 minutes (×500). (B) Inset of Figure 3A. Note no remarkable change (×2,000).
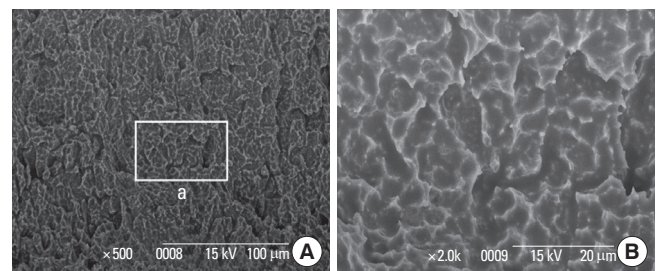

Figure 7. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 140 mJ/pulse for 2 minutes (×500). (B) Inset of Figure 7A. Flattened surface is observed (×2,000).

Figure 4. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 100 mJ/pulse for 2 minutes (×500). (B) Inset of Figure 4A. Melted surface is observed (×2,000).
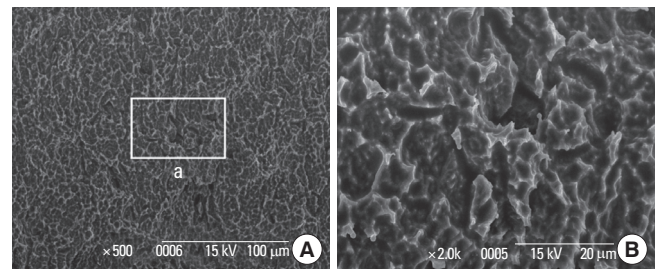

Figure 8. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 180 mJ/pulse for 1 minute (×500). (B) Inset of Figure 8A. Melted surface is observed (×2,000).

Figure 9. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 180 mJ/pulse for 1.5 minutes (×500). (B) Inset of Figure 9A. Flattened surface is observed (×2,000).
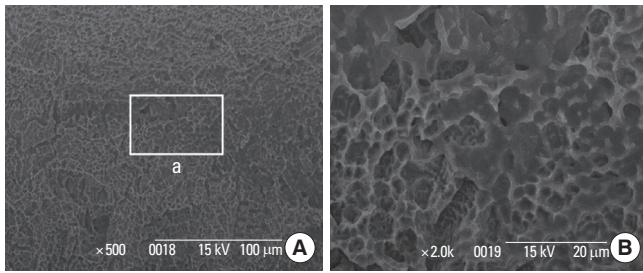

Figure 10. (A) Sand-blasted, large grit, acid-etched implant surface irradiated at 180 mJ/pulse for 2 minutes (×500). (B) Inset of Figure 10A. Flattened surface is observed (×2,000).

DISCUSSION

This study observed changes in the roughness and microstructure of SLA implant surfaces after Er:YAG laser irradiation with varying pulse energy power and application time. The surface roughness values remained unchanged when the implant surface was irradiated at 100 mJ/pulse for 1 minute. However, the Ra values decreased and surface meltdown was observed when the application time increased to 1.5 and 2 minutes under the same pulse energy power. All of the roughness values decreased with a pulse energy power above 140 mJ/pulse regardless of the application time and showed meltdown and flattening of the irradiated implant surfaces. Such surface changes were more notable as the pulse energy and the application time increased. However, the differences in Ra values were not statistically significant ($P > 0.05$).

The most common implant-related complications are peri-implant diseases associated with inflammatory conditions affecting tissues surrounding dental implants. The diseases can be classified into peri-implant muscositis and peri-implantitis [5]. The former is a reversible inflammation affecting soft tissues surrounding functional implants, while the latter is an inflammation which may result in the loss of supporting bones and soft tissues. Fransson et al. [31] reported a 27.8% prevalence of peri-implantitis, while Roos-Jansåker et al. [32] suggested that at least 56% of the subjects exhibited sites with peri-implantitis.

The ultimate goal of peri-implantitis treatment is to establish re-osseointegration of exposed implant surfaces. Roughened implant surfaces may contribute to favorable osseointegration, but they present a more difficult environment for microbial plaque removal once they are infected with peri-implantitis [33].

Kreisler et al. [11] found that implant surface changes at different laser irradiation energies varied with the type of surface, suggesting that the intensity of an Er:YAG laser should be adjusted according to the type of implant surface. Therefore, this study aims to propose an adequate energy intensity
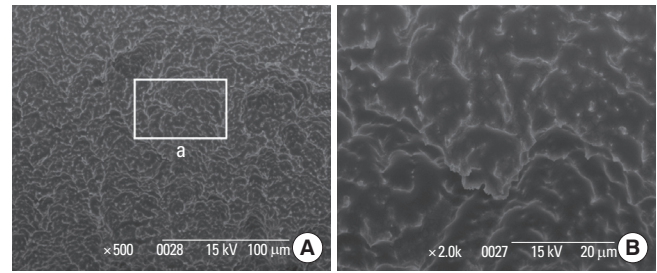
and application time for effectively detoxifying infected SLA implant surfaces without causing changes in the implant surfaces.

Er:YAG laser irradiation at 100 mJ/pulse and 10 Hz did not raise the temperature over 47°C, which could damage surrounding tissues [34,35]. Kreisler et al. [23] reported that the number of bacteria decreased by more than 98 percent on various implant surfaces contaminated with *S. sanguinis* when irradiated with an Er:YAG laser at 10 Hz with an intensity of 60 or 120 mJ/pulse for one minute. In addition, Schwarz et al. [36] suggested that laser irradiation at 100 mJ/pulse and 10 Hz on SLA implant surfaces removed plaque on the surfaces more effectively than plastic curettes. Schwarz et al. [30] found that cultured osteoblast-like cells from sarcoma on various implant surfaces, irradiated with a laser intensity of 100 mJ/pulse and 10 Hz for 60 seconds, showed cell adhesion in a larger area than on implant surfaces detoxified with an ultrasonic scaler without any morphologic change. Kreisler et al. [11] detected alterations in SLA surfaces irradiated by Er:YAG at 130 mJ/pulse for 5 seconds in a single spot. Based on previous studies and this experiment, laser irradiation at 100 mJ/pulse and 10 Hz for 1 minute is suggested as a standard for detoxification of implant surfaces.

Kreisler et al. [11] applied a laser for 5 seconds to each implant with a surface area of 0.229 mm² in their study to determine the effect of Nd:YAG, holmium:YAG, Er:YAG, CO_2, and GaAIAs on the surface of endosseous dental implants. In this study, the total irradiated surface area was 2×2 mm² and the radius of the laser tip used was 540 μm. To ensure 5 seconds of laser irradiation for every spot, the irradiation time was converted to 87 seconds, that is, about 1.5 minutes. With 1.5 minutes as the reference time, the laser application time was set to 1 minute, 1.5 minutes and 2 minutes.

In this study, the pulse energy and application time were the only variables controlled during the irradiation. In actual clinical situations, an irradiation angle of 90° from the implant surface is only possible after flap elevation. Thus, alteration in the irradiation angle is inevitable to perform laser

therapy on patients, and the intensity of the laser energy will change accordingly with the angle change. Further investigation should be conducted to determine the effects of different irradiation angles on the energy intensity transmitted to the implant surfaces and provide guidelines for clinical situations.

The SLA surface used in this study, Friadent plus, was created by grit-blasting with corundum of 354 to 500 μm and thermal etching with HCl, H_2SO_4, HF, and oxalic acid. In the process of grit-blasting, pores of 3 to 5 μm in diameter and 2 to 3 μm in depth with micropores of 0.5 to 1 μm in diameter within the pores are created on the surfaces. They form a unique honeycomb-shaped surface. The study by Sammons et al. [37] reported the Ra value of the surface roughness to be 2.75 μm (±0.46 μm) using the same implants, while the average surface roughness in this study was 2.057 μm (±0.408 μm). It is presumed that the difference in numbers can be ascribed to the different areas measured and different measuring methods. Wennerberg and Albrektsson [38] reported that in general, the surface roughness values on the tops are larger than those for the valleys or flanks. In this study, the surface roughness of valleys was measured, resulting in a smaller value compared to those commonly reported.

Based on measurements by optical interferometers and Gaussian filters, Albrektsson and Wennerberg [39] classified the surface roughness values into four groups: 'smooth surface' for roughness values under 0.5 μm, 'minimally rough surface' for roughness values between 0.5 and 1 μm, 'moderately rough surface' for values between 1 and 2 μm, and 'rough surface' for values over 2 μm [40]. Wennerberg and Albrektsson [38] suggested an ideal roughness range for implants to be between 1 and 1.5 μm. The SLA implant surface roughness used in this study belongs to the 'rough surface' category, with surface roughness just over 2 μm, and the roughness value decreased after irradiation to 1.871 μm (±0.384 μm), and this falls into the 1 to 2 μm range, an optimum condition for osseointegration.

In this study, changes on the SLA implant surfaces were detected when the surfaces were irradiated with an Er:YAG laser with the intensity of 100 mJ/pulse for 2 minutes. The findings showed that laser irradiation with 100 mJ/pulse for less than 1.5 minutes is recommended for optimum results without causing changes to the SLA surface.

Although this study was conducted with the energy intensity of the laser and application time as the only variables, available variables include frequency, distance, angles of irradiation, and the sizes and shapes of the stylus tips of the laser. Therefore, further studies based on additional variables should be conducted to verify the effects of Er:YAG lasers, and the effects of altered surfaces on cell adhesion and re-

osseointegration should also be investigated.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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