Research Article

JPIS Journal of Periodontal & Implant Science

J Periodontal Implant Sci 2011;41:234-241 • http://dx.doi.org/10.5051/jpis.2011.41.5.234

The effect of erbium-doped: yttrium, aluminium and garnet laser irradiation on the surface microstructure and roughness of double acid-etched implants

Ji-Hyun Kim[1], Yeek Herr[1,2], Jong-Hyuk Chung[1,2], Seung-Il Shin[1,2], Young-Hyuk Kwon[1,2,*]

[1]Department of Periodontology, [2]Institute of Oral Biology, Kyung Hee University School of Dentistry, Seoul, Korea

Purpose: One of the most frequent complications related to dental implants is peri-implantitis, and the characteristics of implant surfaces are closely related to the progression and resolution of inflammation. Therefore, a technical modality that can effectively detoxify the implant surface without modification to the surface is needed. The purpose of this study was to evaluate the effect of erbium-doped: yttrium, aluminium and garnet (Er:YAG) laser irradiation on the microstructural changes in double acid-etched implant surfaces according to the laser energy and the application duration.

Methods: The implant surface was irradiated using an Er:YAG laser with different application energy levels (100 mJ/pulse, 140 mJ/pulse, and 180 mJ/pulse) and time periods (1 minute, 1.5 minutes, and 2 minutes). We then examined the change in surface roughness value and microstructure.

Results: In a scanning electron microscopy evaluation, the double acid-etched implant surface was not altered by Er:YAG laser irradiation under the condition of 100 mJ/pulse at 10 Hz for any of the irradiation times. However, we investigated the reduced sharpness of the specific ridge microstructure that resulted under the 140 mJ/pulse and 180 mJ/pulse conditions. The reduction in sharpness became more severe as laser energy and application duration increased. In the roughness measurement, the double acid-etched implants showed a low roughness value on the valley area before the laser irradiation. Under all experimental conditions, Er:YAG laser irradiation led to a minor decrease in surface roughness, which was not statistically significant.

Conclusions: The recommended application settings for Er:YAG laser irradiation on double acid-etched implant surface is less than a 100 mJ/pulse at 10 Hz, and for less than two minutes in order to detoxify the implant surface without causing surface modification.

Keywords: Dental implants, Peri-implantitis, Lasers.

INTRODUCTION

As dental implant therapy has become more common, many original products have been flowing onto the dental implant market. Their common aim is to develop an implant design that can achieve faster and more stable osseointegration during a short period of time, and a higher success rate over time. However, as better results and higher success rates are reported annually, implant-related complications have also been increasing. One of the most frequent complications is

Received: Jul. 24, 2011; **Accepted:** Sep. 17, 2011

***Correspondence:** Young-Hyuk Kwon
Department of Periodontology, Institute of Oral Biology, Kyung Hee University School of Dentistry, 1 Hoegi-dong, Dongdaemun-gu, Seoul 130-701, Korea
E-mail: kyhyuk@khu.ac.kr, Tel: +82-2-958-9380, Fax: +82-2-958-9387

www.jpis.org
pISSN 2093-2278
eISSN 2093-2286

peri-implantitis, which affects an osseointegrated implant in function, and results in a loss of supporting bone [1]. Peri-implantitis can be caused by either a bacteria-induced inflammatory process [2] or an occlusal overload [3,4]. Regarding the former etiology, the characteristics of an implant's surface are closely related to the progression and resolution of inflammation [5]. If the surface is contaminated with bacteria and endotoxin, then biologic repair cannot occur while those contaminates are present [6]. In the course of detoxification, inappropriate methods may damage the implant surface resulting in compromised repair [7,8]. Considering these factors together, a technical modality for peri-implantitis treatment that can effectively detoxify the surface without causing modifications to the surface is needed.

Erbium-doped: yttrium, aluminium and garnet (Er:YAG) laser has recently gained attention for its potential over other techniques because of its advantageous properties including excellent tissue ablation [9,10], a high bactericidal ability [11] and a detoxification effect that does not cause tissue damage or temperature elevation [12]. Due to the advantages, the Er:YAG laser would have great potential for application to the treatment of peri-implantitis [13]. The various types of implant surfaces make it necessary to find the most ideal laser application conditions. The purpose of this study was to evaluate the effect of Er:YAG laser irradiation on the microstructure of double acid-etched implant surfaces according to the laser energy and the application duration.

MATERIALS AND METHODS

Implants

Ten double acid-etched implants (Osseotite, Biomet, Inc., Palm Beach Gardens, FL, USA) of a diameter of 6.0 mm and a length of 15 mm were used in this study. Specifically, the surface texture of the implants was produced by thermally etching smooth titanium with hydrochloric and sulfuric acid at a temperature of 100°C.

Laser system

The applied laser system was an Er:YAG laser (KEY3, KaVo Dental GmbH, Biberach, Germany) emitting pulsed infrared radiation at a wavelength of 2.94 μm with a truncated cone tip. The Er:YAG laser has a variable pulse frequency (1 to 15 pps) and pulse energy (60 to 260 mJ).

Surface evaluation

To qualitatively evaluate the implant surface topography, we used a scanning electron microscope (S-2300, Hitachi Co., Tokyo, Japan). A mechanical contact profilometer (Form Talysurf Laser 635, Taylor Hobson, Leicester, UK) with a contact stylus instrument made of diamond was also used to present roughness data by using standard numeric roughness parameters.

Specimen assignment

Among the ten double acid-etched implants, one was assigned to the control group which was not irradiated; the others were assigned to the test group that was irradiated with different energy and time conditions. The test group was divided into three subgroups according to the laser application energy (100 mJ, 140 mJ, and 180 mJ). Three different irradiation times (1 minute, 1.5 minutes, and 2 minutes) were then applied to each subgroup (Fig. 1).

Surface roughness measurement before laser application

In order to fix the implant in position, an implant container was first constructed with impression putty. When the measurement point was marked by a water-proof pen on the container, the surface roughness on each implant was then measured three times on the 3rd, 6th, and 9th valley by using a mechanical contact profilometer. A profilometer was used to measure and record the average roughness (Ra), one of the height-descriptive and two-dimensional parameter profiles, using a diamond-tipped stylus of 5 μm radius running horizontally to the long axis of the implant.

Laser application and surface roughness re-measurement

Nine implants were assigned to three test groups, with three implants per group. Group 1 implants were each irradiated with the Er:YAG laser set at a 100 mJ/pulse, 10 Hz, and with applied durations of 1 minute, 1.5 minutes, and 2 minutes. Group 2 was irradiated at 140 mJ/pulse and group 3 was irradiated at 180 mJ/pulse; both groups used the same 10 Hz setting and time protocol as group 1. Each laser irradiation area was 2×2 mm^2 on the 2nd to 4th, 6th to 8th, and 10th to 12th valleys of the implant (Fig. 2). The implant was irradiated under water irrigation using the laser beam and the fiber tips were guided parallel to the implant surface in near-contact mode, which allowed the working distance between the tip of the laser and the exposed surface to be approximately 0.5 mm. The angle between the fiber tips and implant surface was 90° and the laser handpiece was moved along the horizontal, vertical, and oblique pathways repeatedly to provide an even laser exposure to the surface. The laser-irradiated implants were then dehydrated and surface roughness was re-measured on the treated area.

Scanning electron microscopy (SEM) observation

The implants were sputter-coated with a thin layer of gold for 10 minutes and examined using SEM with a magnifica-

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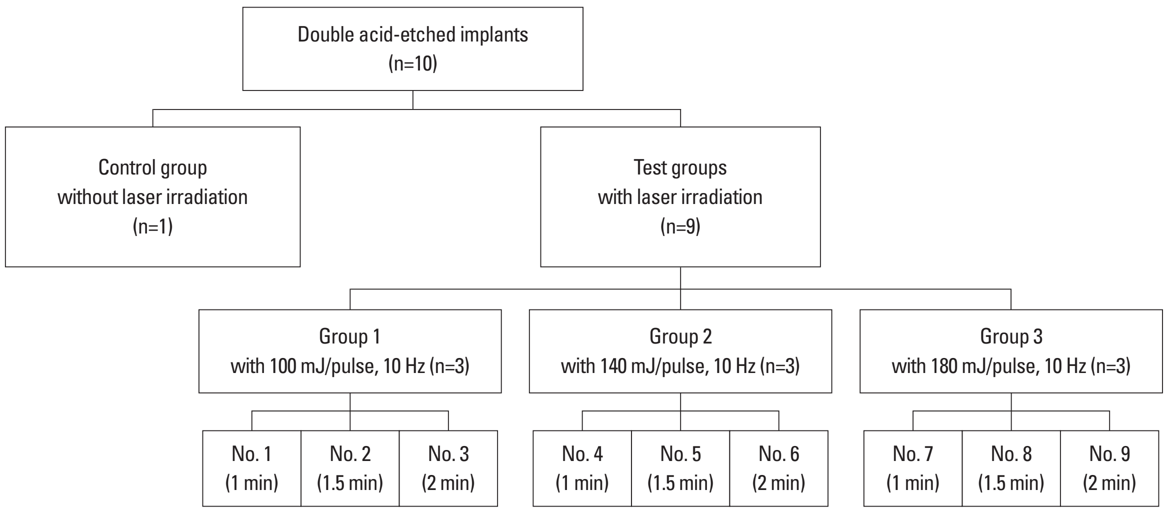

Figure 1. Specimen assignment depending on laser irradiation conditions.

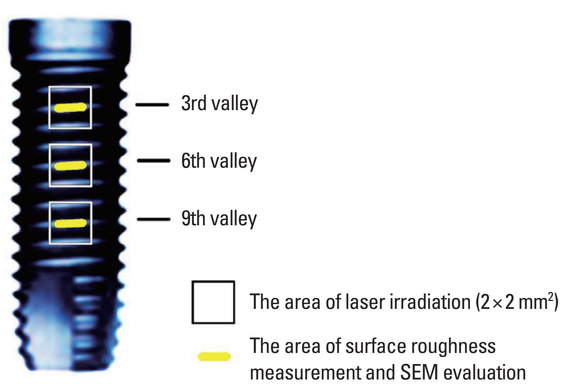

Figure 2. The area of treatment and measurement. SEM, scanning electron microscopy.

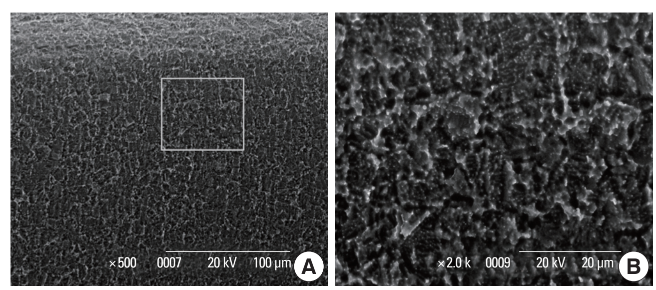

Figure 3. Control specimen: double acid-etched implant surface without any conditioning. (A) ×500, (B) ×2,000. A microstructure consisting of ridges and valleys can be seen.

tion of ×500 and ×2,000. The changes of implant surface roughness were evaluated by examining the SEM images.

Statistical analysis

The SPSS ver. 17.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. Mean values and standard deviations were then calculated for the implant surface roughness. Group comparison was performed by the Wilcoxon signed rank sum test and differences between before and after the laser irradiation were considered to be significant when $P<0.05$.

RESULTS

SEM evaluation

Control group

One double acid-etched implant that was not laser-treated was evaluated using SEM under a magnifying power of ×500 and ×2,000. The isotropic microstructure consisted of sharp, pointed long ridges and v-shaped valleys (Fig. 3).

Test groups

Group 1 (100 mJ/pulse, 10 Hz) showed some partial changes after the two-minute irradiation treatment, but did not show significant changes in the specific ridge and valley structures (Figs. 4-6). After the laser energy was increased to 140 mJ/pulse, the sharpness of the ridges tended to be reduced (Figs. 7-9). As a result of the collapse of the ridges the microstructure of ridges and valleys had been gradually flattened with increased laser energy and irradiation time.

This flattening was more significant with the energy setting at 180 mJ/pulse, which flattened ridges that had still been present after only one minute of irradiation treatment (Figs. 10-12).

The change of microstructure can be easily noted in the oblique view of the surface (Fig. 13).

Surface roughness measurement

The mean surface roughness of the control implant was 0.423±0.039 μm. The amount of change in roughness between before and after the laser irradiation was -0.119 μm, -0.027 μm, -0.173 μm, -0.038 μm, -0.028 μm, -0.013 μm,

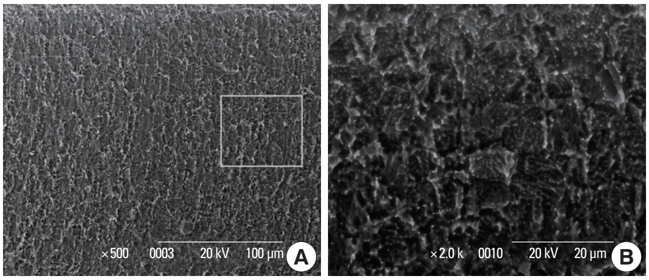

Figure 4. Double acid-etched implant surface irradiated under 100 mJ/pulse for 1 minute. (A) ×500, (B) ×2,000. No remarkable changes are visible.

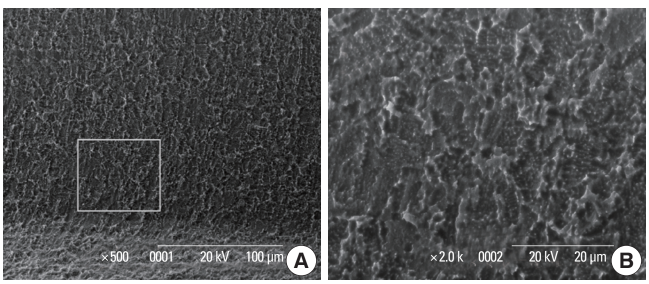

Figure 5. Double acid-etched implant surface irradiated under 100 mJ/pulse for 1.5 minutes. (A) ×500, (B) ×2,000. No remarkable changes can be seen.

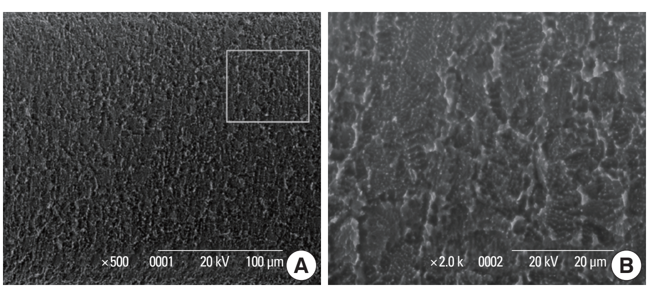

Figure 6. Double acid-etched implant surface irradiated under 100 mJ/pulse for 2 minutes. (A) ×500, (B) ×2000. No remarkable changes can be seen.

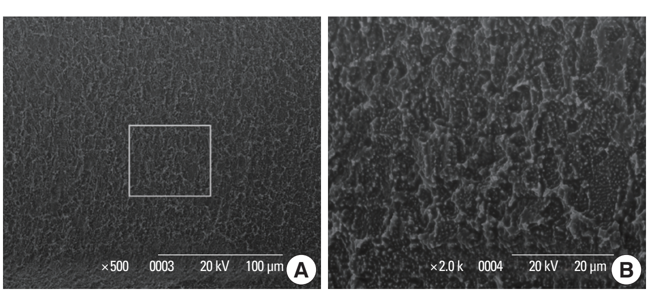

Figure 7. Double acid-etched implant surface irradiated under 140 mJ/pulse for 1 minute. (A) ×500, (B) ×2,000. The sharpness of ridges is reduced.

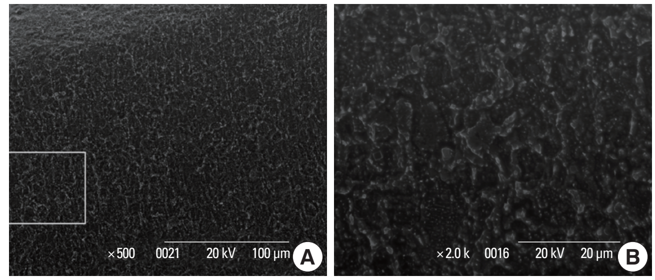

Figure 8. Double acid-etched implant surface irradiated under 140 mJ/pulse for 1.5 minutes. (A) ×500, (B) ×2,000. The change is extensive.

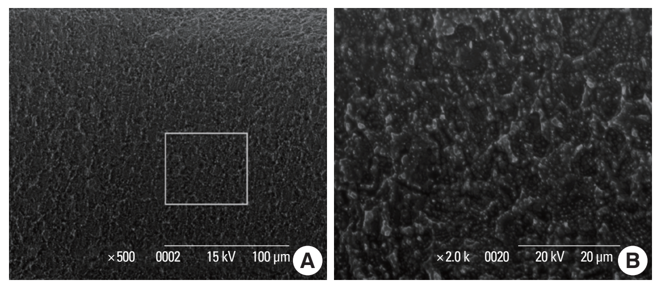

Figure 9. Double acid-etched implant surface irradiated under 140 mJ/pulse for 2 minutes. (A) ×500, (B) ×2,000. The change is extensive.

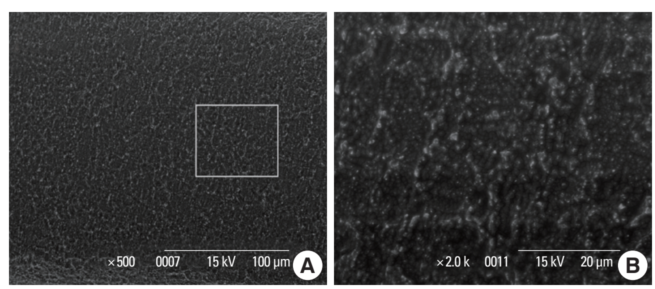

Figure 10. Double acid-etched implant surface irradiated under 180 mJ/pulse for 1 minute. (A) ×500, (B) ×2,000. The loss of the ridges is visible.

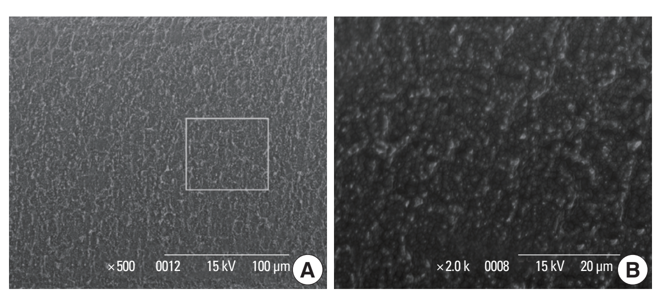

Figure 11. Double acid-etched implant surface irradiated under 180 mJ/pulse for 1.5 minutes. (A) ×500, (B) ×2,000. The change is extensive.

-0.002 μm, -0.044 μm, and -0.003 μm, for experimental group implants from No. 1 to No. 9 in order. All the average roughness values were reduced, regardless of the irradiation energy and time. However, these changes were not statisti-

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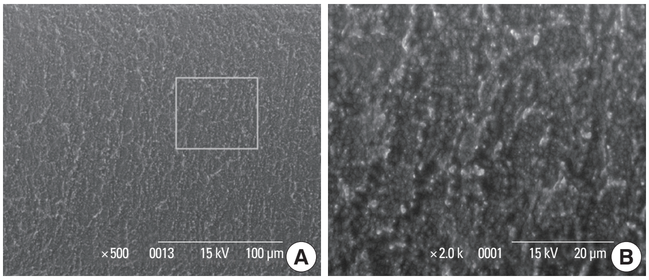

Figure 12. Double acid-etched implant surface irradiated under 180 mJ/pulse for 2 minutes. (A) ×500, (B) ×2,000. The change is extensive.

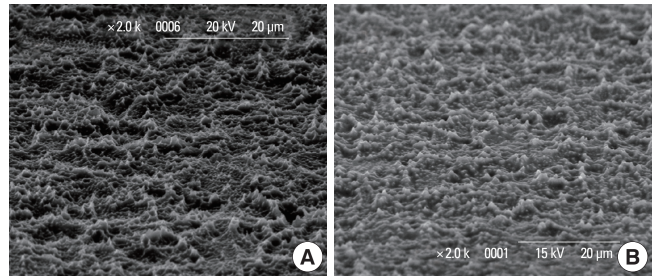

Figure 13. The comparison from the oblique perspective ×2,000 (A) control (B) 180 mJ/pulse, 10 Hz, 1.5 minutes.

Table 1. Surface roughness values measured 3 valleys before and after surface detoxification by laser treatment (mean ± SD).

	Pulse energy (time)	Ra-pre (m)	Ra-post (m)	*P*-value
No.1	100 mJ/pulse, 1 min	0.467±0.135	0.348±0.011	0.109
No.2	100 mJ/pulse, 1.5 min	0.382±0.059	0.355±0.029	0.285
No.3	100 mJ/pulse, 2 min	0.506±0.091	0.333±0.051	0.109
No.4	140 mJ/pulse, 1 min	0.432±0.05	0.394±0.036	0.593
No.5	140 mJ/pulse, 1.5 min	0.409±0.082	0.381±0.07	0.593
No.6	140 mJ/pulse, 2 min	0.420±0.102	0.407±0.075	0.593
No.7	180 mJ/pulse, 1 min	0.410±0.007	0.408±0.068	1
No.8	180 mJ/pulse, 1.5 min	0.419±0.026	0.375±0.001	0.109
No.9	180 mJ/pulse, 2 min	0.399±0.045	0.396±0.015	1

Wilcoxon's signed rank sum test ($P>0.05$).

cally significant ($P>0.05$; Table 1).

DISCUSSION

To achieve successful implant treatment, a large number of surface modifications including mechanical, topographic, and physicochemical properties have been introduced. Among these properties, surface roughness, which is a topographic property, has been the main focus of dental implant studies for more than a decade [14]. Beginning in the mid-1990s, the general trend related to the surface roughness has changed from using a minimally rough surface to a moderately rough one. Previous experiments demonstrated that rough surfaces promoted both bone anchoring and biomechanical stability, and facilitated better osseointegration when compared to machined [15,16] or very rough surfaces [17,18]. The two theoretical bases are as follows: the biological advantage of increased contact area with blood cells, adherence of more platelets [18,19], and migration of osteogenic cells result in increased contact osteogenesis [20,21]; and the mechanical advantage of enhanced mechanical interlocking between the macromolecules of the implant surface and the bone, which increases bone-to-implant contact, result in greater resistance to compression, tension, and shear stress [22,23]. However, consideration of the negative effects of surface roughness is also necessary. Some implant surface properties promote early plaque formation, resulting in inflammatory reactions around implants, which can in turn result in implant failure [24]. In general, a higher degree of bacterial adhesion has been observed on rougher surfaces, which can hinder effective access for cleaning infected implants [25,26]. To achieve the successful treatment of a peri-implantitis lesion, it is necessary to not only surgically remove the inflamed tissue and provide antimicrobial therapy, but also provide an efficient procedure for reconstituting the contaminated implant surface without modifying the surface, to allow for healthy tissue remodeling at the implant interface [27]. Although it is reported that some mechanical and chemical methods are inappropriate, in that they cause surface damage, it can be mostly prevented by using controlled methods including some types of dental lasers [28,29].

Among the various laser systems, the Er:YAG laser has been recognized as the most promising laser system for obtaining excellent tissue ablation with high bactericidal [30] and detoxification effects [31,32]. Higher energy levels to achieve even more potent effects, as mentioned above, can lead to rapid heat generation, which creates tissue and implant surface damage [33]. However, during irradiation the specific wavelengths of an Er:YAG laser will not result in a significant increase in implant body temperature because they are poorly absorbed by titanium. In addition, due to the implant irradiation occurring under sufficient water cooling, the Er:YAG laser affects only the superficial layer without affecting the deep regions of a substrate, since the applied energy is transferred into a thermal reaction leading to the evaporation of the coolant. Depending on the different implant surfaces and laser irradiation conditions, the effects of an Er:YAG laser can vary and these have been evaluated in previous series studies [34-36].

The present study was performed to evaluate the effects of Er:YAG laser irradiation on the double acid-etched implant surface microstructure, according to the laser energy and the application duration. The following was the experimental protocol. The energy setting and irradiation exposure duration was determined based on the conditions that do not allow harmful heat generation or surface alteration, but allow effective cytotoxicity and biocompatibility; the method of irradiation such as the irradiation angle, the distance from the implant surface, and the course of tip movement were determined by considering clinical situations.

The SEM image evaluation of this study showed that the original structure of the double acid-etched implant was not changed by the treatment condition of 100 mJ/pulse, at 10 Hz, with applied durations of 1 minute, 1.5 minutes, and 2 minutes. Increased laser energy of 140 mJ/pulse and 180 mJ/pulse caused surface alteration that resulted in reduced sharpness of ridge structures. However, neither melting nor cracking was observed, and the subtractive surface treatment may have higher stability than additive surface treatment, specifically laser irradiation. In additive surface treatment such as plasma spray-coating of hydroxyapatite particles, titanium beads, or physical or chemical vapor deposition, deposited particles may have a tendency to cause resorption or separation of the coating. On the other hand, the acid-etching and blasting methods, which are subtractive surface treatments, did not show significant surface change and endured higher energy conditions.

The surface roughness evaluation revealed that the roughness value of the non-laser irradiated double acid-etched implant used in this study was as low as that of the machined implant. That is, except one specimen (No. 3), all implants had a low roughness value (Ra < 0.5 μm) that could be classified as a smooth surface according to the surface topography characterization advanced by Albrektsson and Wennerberg [14]. Although the kinds of measurement methods and implant surface area are not identical, the results are different from other experiments, and this showed that the double acid-etched implant system (Osseotite, Biomet, Inc.) had minimal roughness values (0.5 μm < Sa < 1.0 μm) similar to those of turned implants (Table 2). To explain this discordance, understanding of roughness parameters is necessary.

The two-dimensional (Ra) and three-dimensional (Sa) parameters of average height deviation are recognized as being quite stable and insensitive to occasional high peaks or deep valleys, and are the most commonly used parameters in evaluating implant surface roughness [37]. However, 3-D topographic analysis using an optical interferometer is superior to 2-D analysis because the former (Sa) is more accurate, representative, and flexible. Mechanical contact profilometer disadvantages are that there is no precise information about which regions were actually measured and it cannot be used for non-destructive evaluations of implants because the tip cannot evaluate threaded parts. Therefore, the use of 3-D evaluations is recommended for implant surface evaluation. As the surface roughness in the screw-type implant varies at different locations, the roughness of all these regions must be considered when surfaces of oral implants are evaluated. It is widely accepted that the nine measurements on each screw (three tops, three valleys, and three flanks) of three implants are sufficient to obtain a reliable mean value [38]. In this study, we evaluated surface roughness on only three valleys using a mechanical contact profilometer. The reason only three valleys were measured was to evaluate the roughness changes on the same area where SEM evaluation was done. Therefore, it must be noted that the roughness value of the double acid-etched implant in this study does not represent the overall surface, but a restricted valley area. In other words, we cannot claim that this implant system had a smooth surface nor that the overall surface roughness was not changed significantly by laser irradiation. Compared with a previous study [39] conducted with the same protocol of this study, except for the detoxification method (rubbing with 50 mg/mL tetracycline-HCl) and the evaluation method of surface roughness (optical interferometer), the mechanical contact profilometer in this study showed more reproducible and consistent results than that of the optical interferometer. This suggests that mechanical contact profilometer use is a possible method for some areas of implant dentistry (e.g., in confined, rather than flat surface measurement).

It is necessary to consider some limitations to this study. First, although SEM provides high-quality images, it is more suitable for morphologic than topographic description. Topographic characterization is almost exclusively used as a comparative method and is therefore prone to subjective interpretations. There was also an ambiguous interpretation in this study concerning whether or not the change was examined (Fig. 4). Therefore, a more objective parameter is needed. Second, in this study, roughness measurement was evaluated by a mechanical contact profilometer on valleys. In order to evaluate the entire implant surface, a topographic surface analysis must be used, including three thread tops, three thread valleys, and three flank areas using an optical interfer-

Table 2. The comparison of mean roughness value of double acid-etched implants (Osseotite, Biomet, Inc., Palm Beach Gardens, FL, USA).

	Roughness mean value (Sa, μm)[a]
Abrahamsson et al. 2001 [34]	0.94[b]
Albrektsson and Wennerberg 2004 [14]	0.5-1.0[b]
Sul et al. 2006 [35], 2008 [36]	0.72[b]

[a]All roughness value was evaluated by the optical interferometer.
[b]Roughness mean value was obtained on tops, valleys, and flanks.

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ometer. Third, because of the physical basis of the methods, all measuring systems, irrespective of being 2-D or 3-D, have vertical and lateral limitations in terms of measuring range and resolution; the true surface topography will never be obtained due to surface deformation in the mechanical contact mode techniques and because of optical artifacts in optical instruments. Fourth, integral roughness parameters are of very limited value in describing the complex surface structures presented on surface-treated titanium implants. In addition, though surface roughness has been regarded as a predominant factor in cell adhesion and osteogenesis during the implant healing phases, no correlation was reported between the profilometry data and bone contact percentage. Double acid-etched implants have been recognized as having a minimally rough surface, have been reported to induce more bone contact, and have a 3.5-fold increase in mechanical pull-out force compared to untreated implants, possibly as a result of better fibrin clot retention and growth factor enhancement. Overall, some other factor dictating cell adhesion and bone apposition in direct contact with the implant surface, other than roughness, should be considered. Fifth, only the topographic characterization was studied in relation to the microstructure change contained in this study; therefore, additional research is needed to evaluate the effect of the Er:YAG laser on cell attachment and bacteria removal on the implant surface. Simply roughening the implant surface may not result in a large change in bone conductivity and biologic response; there may be more critical parameters of biocompatibility than surface roughness.

Standardization is needed for peri-implantitis treatment to determine under which conditions the Er:YAG laser can be used without altering the implant surface. In conclusion, Er:YAG laser irradiation on a double acid-etched implant surface is recommended to be set below 100 mJ/pulse, at 10 Hz, and with an applied duration of less than two minutes for detoxification of the implant surface in order to prevent surface alteration.

CONFLICT OF INTEREST

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

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