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ORIGINAL ARTICLE

The effect of Er,Cr:YSGG laser irradiation on titanium discs with microtextured surface morphology

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Abstract Both mechanical and chemical methods can be used to clean and decontaminate implant surfaces. Incomplete debridement of infected tissue and failure to clear endotoxins can result in graft failure and a return of the defect. Recently, lasers have gained popularity for sterilizing and cleaning implant surfaces. We determined the effects of laser treatment on the surface characteristics of titanium discs with a Laser-Lok surface. The discs were irradiated with an erbium, chromium: yttrium, scandium, gallium, garnet (Er,Cr:YSGG) laser under various conditions (R1-9). Scanning electron microscopy was used to evaluate the surface. Considerable surface alterations such as melting and flattening were seen at R6 (2 W, 20 Hz, 4 mm, 45 s) and R8 (3 W, 25 Hz, 2 mm, 45 s). In addition, cracking was seen at R8. The laser parameters should be optimized to conserve surface characteristics during the irradiation of implant surfaces.

Keywords Peri-implantitis · Er,Cr:YSGG laser · Ti disc · Laser-Lok surface

Introduction

For many years, dentists have been honing the techniques involved in successful dental implantation [1]. However, complications such as soft-tissue inflammation, bone resorption, and ultimately, the loss of the implant, compromise the quality and quantity of the soft and hard tissues surrounding the implant [2]. It is especially important to disinfect the implant surface properly. In addition, mechanical treatment of the implant body can alter its surface, delaying or preventing bone regrowth [3]. Incomplete debridement of infected tissues and the failure to clear endotoxins can result in graft failure and a return of the defect [4]. Other mechanisms leading to failure include a temperature increase at the implant site, altered implant surface roughness, or low titanium biocompatibility [1].

Crestal bone resorption or "dieback" is often observed in dental implants. Multiple causes of this complication have been suggested, such as the need for biological width enlargement and the bacterial and inflammatory cell infiltrate present at the implant abutment junction [5]. Consequently, Laser-Lok surfaces have gained popularity in recent years.

Laser-Lok microchannels are a series of precise circumferential channels that are created using laser ablation. These microchannels are sized optimally to facilitate the attachment and organization of osteoblasts and fibroblasts [6]. The Laser-Lok microstructure includes a repeating nanostructure that maximizes the surface area and enables cell pseudopodia and collagen microfibrils to interdigitate with the surface. Preclinical and clinical studies have aimed to reduce or minimize crestal dieback by elucidating the role that microchannels with defined three-dimensional shapes and depths play in controlling fibroblast and osteoblast behavior by limiting apical migration of the junctional epithelium [7, 8].

The surfaces of virtually all commercial dental implants are roughened using various methods that create random surfaces and alter cell reactions depending on where the cell contacts the surface. These surfaces have greater osseointegration than machined surfaces, but only the Laser-Lok surface is also effective for soft-tissue attachment [9, 10]. The peri-implant connective tissue that is established following implant surgery using a Laser-Lok implant (BioHorizons, Atlanta, GA) acts as an effective barrier to the apical migration of epithelial attachment [5, 11]. In addition, the Laser-Lok microchannels result in a perpendicular, functional physical attachment that helps to stabilize the bone level and reduce the loss of crestal bone [5, 12].

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Table 1 Experimental design generated by Taguchi modeling

	Power (W)	Frequency (Hz)	Distance (mm)	Time (s)
R1	1	20	2	15
R2	1	25	4	30
R3	1	30	6	45
R4	2	20	4	45
R5	2	25	6	15
R6	2	30	2	30
R7	3	20	6	30
R8	3	25	2	45
R9	3	30	4	15

A new generation of erbium, chromium: yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) lasers has been used in combination with water and air to ablate enamel, dentin, bone, and soft tissue [13]. However, no study has examined whether the laser alters the surfaces of titanium implants. The Laser-Lok surface is unique, facilitating connective tissue attachment [12]. If its surface characteristics are altered by using inappropriate laser parameters, reattachment of connective tissue to the implant surface might also be altered. Consequently, it is crucial to determine the laser parameters that do not alter the surface morphology during the decontamination process. However, no data on detoxification methods for Laser-Lok surfaces have been reported. Therefore, we evaluated the changes in surface morphology after Er,Cr:YSGG laser irradiation.

Materials and methods

Ten 15-mm-diameter, 1-mm-thick Grade V titanium discs with Laser-Lok (BioHorizons) surfaces were irradiated with an Er,Cr:YSGG laser (BIOLASE, Irvine, CA). Scanning electron microscopy (SEM; EVO LS10; Zeiss, Cambridge, UK) was used to evaluate disc surface topography.

Laser treatment

An acrylic container was designed to hold the discs in position. Another acrylic holder was used to stabilize the laser handpiece. The discs were irradiated under irrigation with 15 % water and 30 % air using the laser beam with the G4 fiber tip perpendicular to the surface in non-contact mode. Nine irradiation parameters were then used for the specimens in each group (Table 1). One disc was not irradiated and constituted a control.

In experiments with four factors and three levels, a full factorial design normally dictates that 81 (34) trials should be performed. Given the large number of experiments required to optimize the numerous parameters, we applied a robust experimental design called the Taguchi method. According to the nine-level orthogonal array produced using this method (Table 1), only nine experiments were required. This method is a combination of mathematical and statistical techniques that can identify experimental conditions with the least variability as optimal conditions. The calculated laser outputs for the different experimental conditions are shown in Table 2.

Surface morphological analysis

To evaluate the titanium surface roughness, the disc surfaces were examined using SEM at ×2000 magnification (Zeiss, Cambridge, UK).

Results

Scanning electron microscopy images of irradiated Laser-Lok samples are shown in Fig. 1. The control sample, which was not irradiated, is shown in Fig. 2. Observable changes such as melting and flattening were seen only at R6 (2 W, 30 Hz, 2 mm, 30 s) and R8 (3 W, 25 Hz, 2 mm, 45 s). In addition, cracking was seen at R7 (Fig. 1).

Table 2 Calculated laser output values

	Spot Size (2r)	Spot Area (mm^2)	Power Density (W/mm^2)	Energy Density ($W*s/mm^2$)	Pulse Energy (W/Hz)	Pulse Duration (μs)	Duty cycle (‰)	Peak Power (W)
R1	0.80	0.50	1.99	29.85	50	140	2.8	357.14
R2	0.90	0.63	1.57	47.18	40	140	3.5	285.71
R3	1.05	0.86	1.15	51.99	33	140	4.2	238.09
R4	1.30	1.32	1.50	67.84	100	140	2.8	714.28
R5	1.40	1.53	1.29	19.49	80	140	3.5	571.42
R6	0.90	0.63	3.14	94.36	67	140	4.2	476.19
R7	2.10	3.46	0.86	25.99	150	140	2.8	1,071.42
R8	1.00	0.78	3.82	171.97	120	140	3.5	857.14
R9	1.40	1.53	1.94	29.24	100	140	4.2	714.28

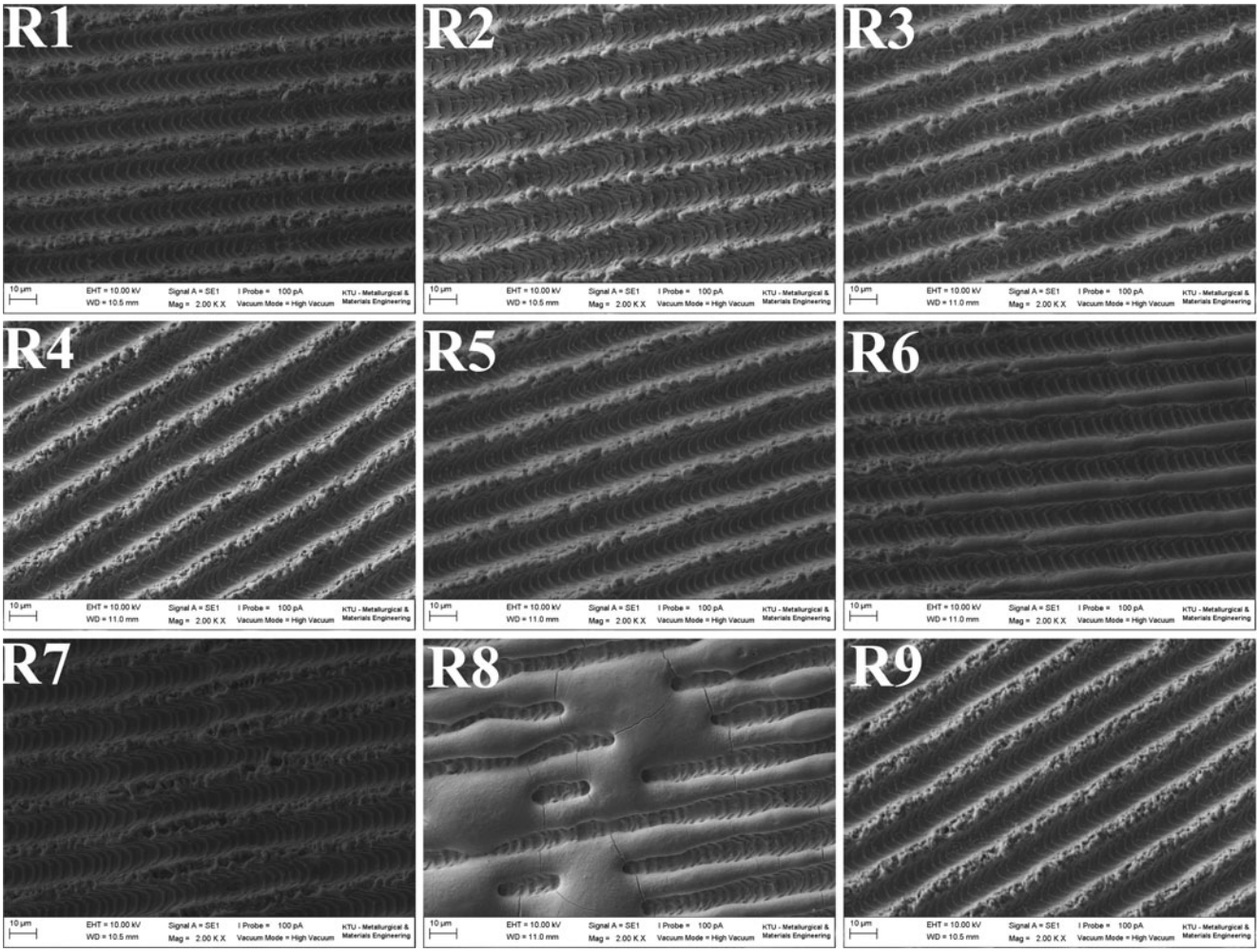

Fig. 1 Scanning electron microscopy images of irradiated Laser-Lok samples

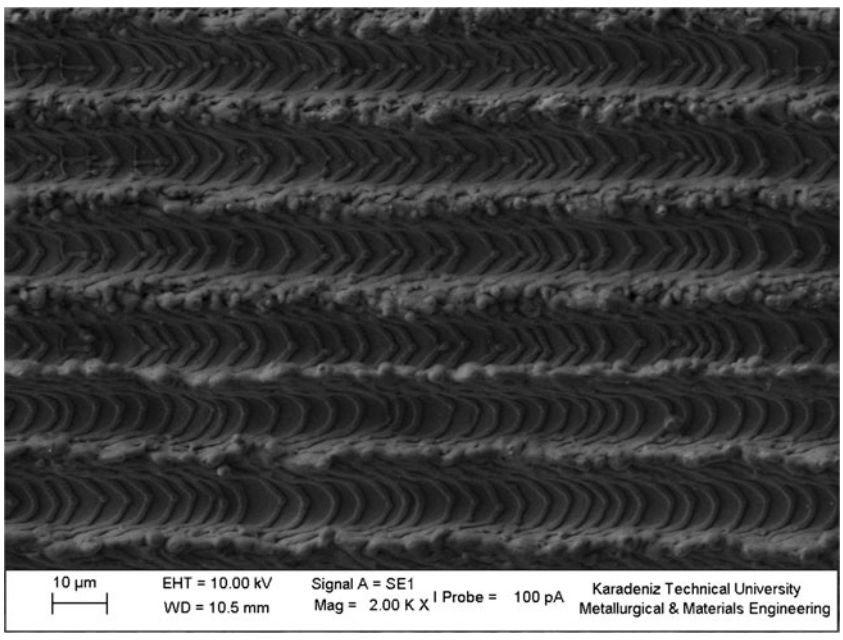

Fig. 2 Control sample (not irradiated)

The power densities of parameters R6 and R8 were 3.14 and 3.82 W/mm^2, respectively. These values were extremely high and resulted in deterioration of the Laser-Lok surfaces. The lowest power densities were 1.15, 1.29, and 0.86 W/mm^2 for experimental conditions R3, R5, and R7, respectively. There were no observable changes at these power densities and these surfaces were similar to the control surface.

Discussion

Both mechanical and chemical methods can be used to clean and decontaminate implant surfaces [14–16]. Insufficient implant decontamination can compromise wound healing after treating peri-implantitis [17]. In recent years, lasers have gained popularity for sterilizing and cleaning of implant surfaces [18–20]. As discussed previously, Er, Cr:YSGG lasers use a combination of laser energy, with water and air being widely used for dental purposes [21–23]. Recently, this laser system has been applied to the modification of Ti surfaces [3, 13, 17, 24]. With the widespread use of lasers for detoxification, it is important to understand their effects on the titanium surface of implants. The Er,Cr:YSGG laser is highly effective for removing contaminants from implants. Most other laser systems function in vaporization mode and the high temperatures can damage the implant surface and result in tissue charring or damage [3].

Optimal laser parameters are essential for preserving the implant surface characteristics. In this study, discs with Laser-Lok surfaces were irradiated using various parameters and distances. Macroscopic surface alterations were seen with parameters R6 and R8 due to the high power densities at these settings. The distance also affects the power density, and hence the surface changes. As a result, clinicians should carefully control the distance between the laser tip and implant surface.

Huang et al. examined Ti disc surfaces that were irradiated with a Er,Cr:YSGG laser using 125 and 190 J/cm^2, in 45 % air and 20 % water [13]. The distance between the tip and surface was almost 2 mm. After laser treatment, melting was observed on the specimen surface. In addition, both the melted area and surface roughness increased slightly as the energy increased. In another study, Ti discs were irradiated at 1, 2, 3, 4 and 5 W, and 20 Hz [24]. The distance from the target was 1.5 mm and the irradiation time was 30 s. The surface showed no changes with irradiation at 1 and 2 W, while alterations such as melting, coagulation, and microfractures were seen with irradiation at 3, 4, and 5 W. Nevertheless, no data regarding the alteration of Laser-Lok titanium surfaces after laser irradiation are available. According to our results, the most harmful parameters were R6 and R8, while the other parameters appeared to have no effect. However, further studies should investigate the behavior of cells on Laser-Lok surfaces after irradiation.

Conclusion

Laser parameters, such as the power and distance between the tip and titanium surface, should be optimized to conserve the surface characteristics during irradiation of implant surfaces. Further studies are needed to determine the effects of these laser parameters on osteoblast and gingival fibroblast behavior.

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Conflict of interest The authors report that they have no conflicts of interest

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