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Impact of Er,Cr:YSGG Laser, Sandblast, and Acid Etching Surface Modification on Surface Topography of Biodental Titanium Implants

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Abstract

Introduction: Several techniques have been used to modify the surface of commercially pure titanium (CPTi) implants to improve osseointegration using lasers, sandblasts, sandblasts with acid etching, and other modalities. For implant-osseointegration, surface features like chemical composition of a surface, topography, and surface energy are essential. The present comparative study aimed to compare the impact of Er,Cr:YSGG laser, sandblasting, and acid etching implant surface modifications on the surface topography, roughness, and element chemical composition of the Ti dental implant.

Methods: Thirty CPTi dental implants were divided into three groups according to the surface modification (n = 10 for each group): Group A: Sandblasting with acid etching (SLActive), group B: Sandblasting, and group C: Er,Cr:YSGG laser surface modifications. The modified surfaces were analyzed using scanning electron microscopy (SEM), profilometer, and energy dispersive x-ray spectrometry (EDS).

Results: One-way analysis of variance (ANOVA) showed that there were significant differences in the mean values of average roughness (Ra) of the three groups ($P < 0.05$). Tukey's post hoc test showed that the average roughness (Ra) of laser-surface modification (group C) of the implant had the highest mean value (2.30 µm) among the different groups, while sandblasted surface modification (group B) of the implant had the lowest mean value (1.39 µm). The SLActive (group A) sandblast with acid etching had a mean value of 1.63 µm. SEM analysis showed that significantly modified surface topographies and different element concentrations were found within all modified groups.

Conclusion: The Er,Cr:YSGG laser irradiation increased the implant surface roughness value after implant surface modification, compared to sandblasts and sandblasts with acid etching application. The observations for the SEM-EDS analysis revealed several elements with different concentrations, which were affected by the physical–chemical characteristics of the surface modification techniques. The SEM analysis showed a significant modification in implant surface topographies of the tested groups.

Keywords: Surface modification; Surface topography; Titanium implant.

Introduction

Materials like metals are frequently used as implants.[1] These materials should have biomechanical characteristics that are equivalent to those of autogenous tissues. The eligibility of Materials for use in biomedical implant applications is determined by such properties as biocompatibility, biofunctionality, bioadhesion, and corrosion resistance.[1] The main metallic biomaterials are stainless steel, cobalt alloys, titanium (Ti), and Ti alloys.[2]

Titanium and Ti alloys are excellent choices of materials in biomedical applications because of their high specific strength and their biocompatibility.[3] Because a persistent and inert oxide layer spontaneously forms on the surface of commercially pure titanium (CPTi) when it is exposed to oxidizing environments, Ti alloys and CPTi are the preferred alloys for making Ti implants.[4,5] The surface modification of dental implants can increase tissue surface layer compatibility and change the chemical characteristics of the surface.[6]

To improve the compatibility of Ti and the osseointegration of surrounding bone structures, numerous techniques related to surface modification have been developed, including laser surface modification, anodization, hydroxyapatite coating, sandblasting, acid etching, or a combination of the two, and Ti plasma spray coating.[7] A key element influencing dental implant osseointegration is roughness. Bone-to-implant contact can be enhanced by a rough surface; variations in the roughness of the implant surface also have a significant influence on the healing of the bone surrounding the

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implant.[8-10] The most popular chemical approach for modifying dental surfaces is acid etching. Acid etching is frequently carried out with hydrofluoric, nitric (HNO_3), sulfuric (H_2SO_4), and mixtures of these acids.[11] However, the ideal level of roughness and superficial morphology are still debatable and require further clarification, and there are several methods in which surface roughness appears to support peri-implant bone repair.[12,13]

The current research aimed to carry out an in vitro qualitative and quantitative assessment of laser ablation, sandblasting, sandblasting with acid-etched implant surface modification utilizing energy dispersive x-ray spectrometry (EDS), a profilometer, and scanning electron microscopy (SEM). The current study's null hypothesis was that the Ti dental surface modifications with different surface modification methods would neither modify surface topographies nor change the surface roughness of the surface zone of Ti dental implant materials.

Materials and Methods

The Ti dental implant investigated in this study was (Dentium®) standard dental implant system (Dentium Co., Ltd. Seoul, Korea), screw-type with a diameter of 4 mm, and 10 mm in length.

A total of 30 CPTi dental implants were randomly divided into three groups according to the surface modification:

- Group A: (n = 10) Ti dental implants sandblasting with acid etching (SLActive) surface modification.
- Group B: (n = 10) Ti dental implants with sandblast surface modification.
- Group C: (n = 10) Ti dental implants with Er,Cr:YSGG laser surface modification.

Sandblasting Surface Modification

Using a dental sandblaster (intraoral) sandblasting device (Air Abrasion Master, Germany), were air-abraded (sandblasted) white aluminum oxide (Al_2O_3) particles of 50 µm particle size onto the surface of the CPTi G4 dental implant. A specially built stand was created to hold the sandblaster and standardize the pre-sandblasted implant surface to be 1.5 cm away from the sandblasting nozzle. The samples were held by the implant adapter by the handpiece of the micromotor. The nozzle was adjusted to be at a 90° angle to the implant surface for 15s at 0.6 MPa (6 bars) of pressure (Figure 1). To remove Al_2O_3 residues from the surfaces of the sandblasted implants, we submerged them in ultra-pure water after sonicating in acetone for 20 minutes.[14]

Sandblasting With Acid Etching (SLActive) Surface Modification

The sandblasting surface of the CPTi G4 dental implant was etched with a warm hydrochloric acid concentration of HCl 37% at 60 ˚C for 5 minutes, rinsed and cleaned by the ultrasonication method in ultra-pure water, and dried. This procedure is used to remove oxide remanent and contamination to obtain a clean and uniform implant surface.[15]

Laser Surface Modification

In this group, the surface of the Ti dental implant was modified by using Er,Cr:YSGG (erbium, chromium: yttrium, scandium, gallium, garnet) laser irradiation (Waterlase MD, Er,Cr:YSGG 2780, USA). The laser was turned on at a wavelength of 2780 nm, set at 100 mJ/pulse, with a power of 2.5 W, frequency of 30 Hz, and pulse duration of 60 seconds, and the MZ6 tip which has a diameter of 600 µm and length of 9 mm was used to deliver the laser energy. Surface modification was carried out by vertical motion, from top to bottom, with an angled tip of the laser handpiece applied to the implant surface with no lateral motion. For a 1-minute time duration, the implant was held by the implant adaptor using the rotary handpiece of the micromotor at 50 rpm in a non-contact mode at a constant distance of 1 mm held by a specially built stand (Figure 2) accompanied by 40% water and

Figure 1. The pre-sandblasted implant surface is 1.5 cm away from the sandblasting nozzle

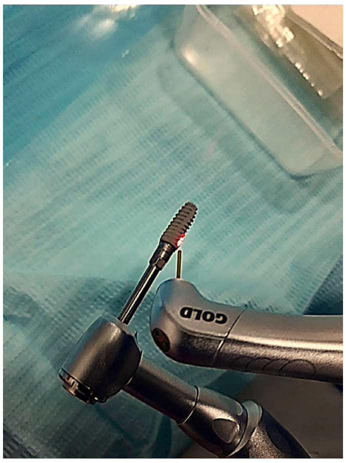

Figure 2. The Distance of 1 mm Between the Laser Tip and the Pre-lasered Implant Surface

50% air spray.[16,17]

Scanning Electron Microscopy

In the present study, SEM (ZEISS Smart SEM version 7.01, SEM Serial Number: EVO 10-800 1014347 Carl Zeiss Microscopy Ltd. Oberkochen, Germany) was used to reveal the topographical and morphological surface properties of the surface of an implant and Al_2O_3 particles grains, using a scanning electron microscope. The Al_2O_3 grains that are sharp and polyhedral are investigated to see how they reduce abrasive wear by breaking along characterized planes during sandblasting. SEM was performed on one specimen at random from each grouping at 20×, 100×, 500×, 2000×, and 5000× magnifications for examination. The working distance was set at 10.0 mm, while the acceleration voltage of the cathode was set to 10.00 kV. Electron SEM images were acquired in a vacuum (10^{-5} bar) to analyze the topographical and morphological surface properties of Ti dental implants. Before imaging in SEM, each implant sample was sputter-coated with a thin layer of gold to avoid sampling charging and microscope beam damage and inserted one by one into a specialized demarcated sectioned base within a vacuum chamber. The focus depth produced by the electron beam of the SEM is larger than a beam of regular light. Therefore, images with very high resolution can be recorded for this reason. Due to its capacity to magnify and reveal details, the SEM is able to analyze specific point positions on the sample.[18]

Elemental Analysis With Energy-Dispersive X-Ray Spectrometry

An X-ray method, also known as EDX (energy dispersive X-ray), is used to determine the elemental composition of the material and perform image analysis. It is interesting to note that by using EDX, for both qualitative and quantitative analysis, users can specify the types of elements present as well as the percentage of the concentration of each element in the sample. To compare the tested exposed samples, EDX studies were carried out with an AV of 10.00 kV, a magnification of 2000, and a working distance of 8.5 mm.[19] The samples were placed on carbon discs and carbon plaster for fixation before being put into a vacuum-sealed microscopy chamber.

Surface Roughness Measurement

The roughness of the test surface was measured using a Portable Intelligent Digital Surface Roughness Tester, Guangdong, China. On a single implant, surface roughness can vary from one area to another. The flank, top, and valley portions of the thread must all have their surface topography measured in screw-type implants. Only a few surface roughness metrics may adequately describe the true implant surface geometry due to its complexity.[20] Using a diamond-tipped stylus with a radius of 5 mm, we measured and recorded the greatest peak-to-valley height of the surface (Rt) and average roughness (Ra) by means of a profilometer with a horizontal axis, in which both the needle and the long axis of the implant were parallel. At constant pressure and speed in a straight line, the surface roughness was measured.

Statistical Analysis

The data were analyzed using SPSS software (SPSS Inc., version 19.0; Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to determine the significant difference between all surface modifications; P values of < 0.05 were considered as statistically significant. The significant groups were compared using Tukey's post hoc test.

Results

Scanning Electron Microscopy Evaluation

In the present study, Figures 3, 4, 5, and 6 showed the SEM surface topographies of Al_2O_3 and CP-Ti implant samples were observed at different magnifications. The Al_2O_3 sandblast particle size distributions and microstructures are shown in Figure 3. SEM scans showed that the 50 µm specification was dominated by both the smallest and largest particles. Only a few of the particles had spherical forms at a magnification of 2000×, and the majority of the particles had grit morphologies with sharp and irregular corners (Figure 3A). The SEM images of the sandblasting particles revealed structural problems such as cracks, microcracks, and more defects visible in the larger particles. It was noted that while some of the 50 µm specified particles were uniformly scattered, others were loosely packed. The sharp and polyhedral grains of Al_2O_3 were visible, which broke during sandblasting and reduced the abrasive wear characteristic (Figure 3B).

In order to provide a point of comparison, SEM images in Figures 4 and 5 showed the surface morphology of implant surface modification by sandblasting, and

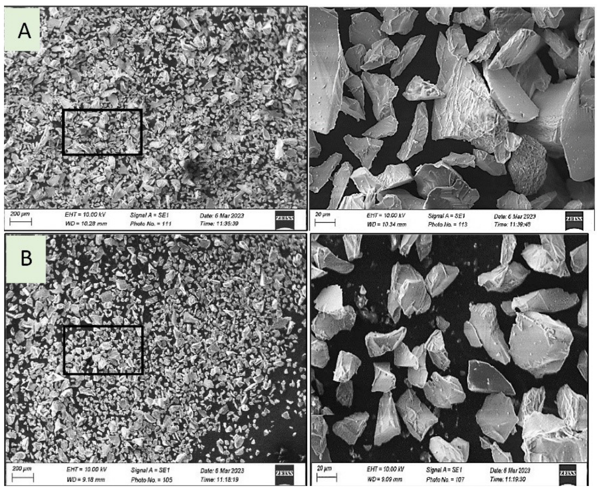

Figure 3. The SEM Images of the Surface Morphology of Al_2O_3 Abrasive. A: Before sandblasting: B: After sandblasting. The finest and the largest particles prevailed in the 50µm

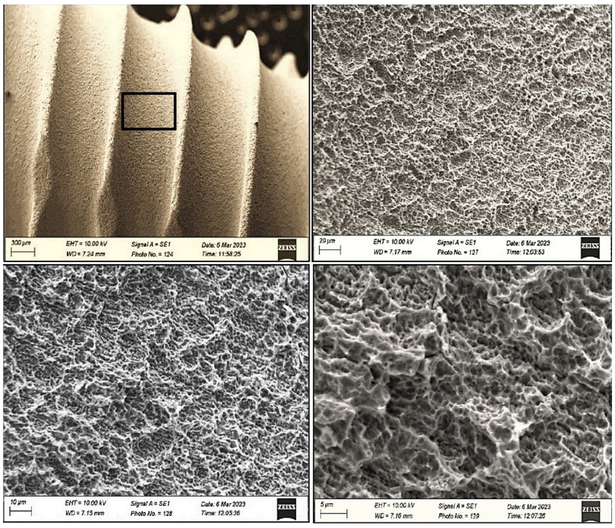

Figure 4. The SEM Images of a Titanium Dental Implant: (SLActive) Surface Modification

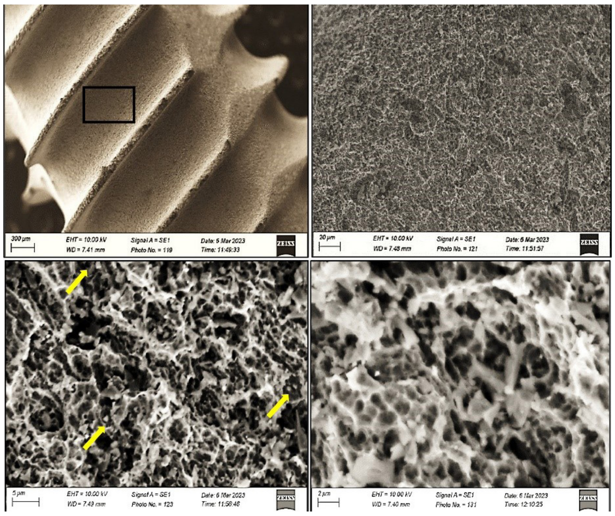

Figure 5. The SEM Images of a Titanium Dental Implant: Sandblast Surface Modification, the Alumina Remnants (Yellow Arrows)

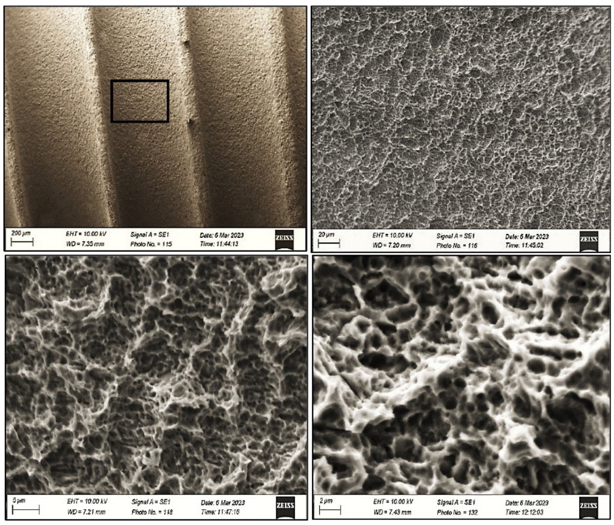

Figure 6. The SEM Images of a Titanium Dental Implant: Laser Surface Modification

sandblasting with acid etching after being sandblasted with 50 µm Al_2O_3 sand at a magnification of 5000 times. In sandblasting surfaces with acid etching, the isotropic microstructure was made up of uneven sharp, long pointed ridges and V-shaped valleys (Figure 4). When surfaces are sandblasted without acid etching (Figure 5), topographical features such as irregular cavities alternated with peaks and valleys in a symmetrical pattern appear similar, acting uniformly across the entire surface. Peaks and valleys with a honeycomb appearance were randomly distributed around the median plane to produce optimum roughness. Implants that had been sandblasted but had not gone through the acid etching process showed alumina remnants with microcracks as well as sharp edges from plastic deformation.

Figure 6 shows SEM images of the surface morphology of a Ti dental implant after laser surface treatment. The modified Ti surface exhibited melting, coagulation, and microfractures, and the laser surface had a porous shape with numerous pores and raised margins that resembled volcanoes. The thin Ti crests that were fused and crushed into flat, smooth plates were visible as melted areas that covered wide sections of surfaces.

Elemental Analysis With Energy-Dispersive X-Ray Spectrometry

Within the limits of the employed measuring technique, the observations for the SEM-EDS studies were made at three various random points on the surface of each sample. The nominal weight composition of CPTi with different surface modifications and Al_2O_3 is reported in Table 1. Chemical analysis of the implants and Al_2O_3 disclosed several elements: Ti, carbon, oxygen, nitrogen, barium, and aluminum. Ti appeared as it was the predominant element after analysis.

Surface Roughness

Data regarding the mean Ra values of the Ti dental implant surface at different Ti surface modifications and SD (standard deviation) of surface roughness values in the three groups and their comparisons are presented in Table 2. Based on the results, different surface modification protocols caused significant differences in the surface roughness of the three groups ($P < 0.05$). For different implant surface modifications, one-way ANOVA showed that there was a significant difference in the mean values of Ra between different surface modifications for all groups ($P < 0.05$) (Table 3). The Ra of the implant sandblasting with acid etching, sandblasting alone, and laser surface modifications were 1.63, 1.39, and 2.30 µm, respectively, while Rt was 10.08, 9.38, and 12.36 respectively.

Discussion

The current research aimed to assess the surface

Table 1. Nominal Weight Composition of Commercially Pure Titanium With Different Surface Modifications and Aluminum Oxide

Material	Group	Composition by Weight %	
Sandblasting with acid etching	A	Ti	98.30
		O	0.50
		Al	1.20
Sandblasting	B	Ti	90.50
		O	1.50
		Al	7.50
		C	0.50
Er,Cr:YSGG laser irradiation	C	Ti	90.10
		O	3.70
		N	4.10
		C	2.10
Al_2O_3 before sanding		C	26.02
		O	42.01
		Al	12.56
		Br	19.40
Al_2O_3 after sanding		C	26.22
		O	41.34
		Al	18.22
		Br	14.22

Abbreviation: Al_2O_3, aluminum oxide.

Table 2. Surface Roughness (Ra, Rt) µm of the Ti implant Surface s in the three groups (n = 10)

	Group	Ra (mean ± SD)	Rt (mean ± SD)	*P* Value*
Sandblast with acid etching	A	1.63 ± 0.20[a]	10.08 ± 0.41	
Sandblast	B	1.39 ± 0.08[a]	9.38 ± 0.37	0.00
Er,Cr:YSGG laser irradiation	C	2.30 ± 0.27[b]	12.36 ± 0.39	

* One-way analysis of variance, Tukey post hoc test at $P \leq .05$. Values with different letters are significantly different.

Table 3. One-Way ANOVA of the Implant Surface Roughness for All Groups With Different Surface Modifications

	P Value	*F* Value	Mean Square	*df*	Sum of Squares
Between groups	2.200	2	1.100 0.041	26.877	0.000*
Within groups	0.491	12			
Total	2.692	14			

*Significant differences, df = degree of freedom.

topography and the relationship between the roughness produced in Ti dental implants based on their surface modification protocol, kind, and the number of chemical elements found on the surface of the implant. The hypotheses in this study proposed in relation to the examined dental implant surface topography are rejected.

In the present study, the SEM examination for the threaded Ti dental implant (Figures 4 and 5) revealed that the V-shaped valleys and long sharp pointed ridges made up the isotropic microstructure regarding the implant surface modifications. The increase in Ra values related to the SLActive (group A) that occurred right away after acid etching was the most noticeable finding in the results of alumina blasting/etching (Table 2). This might be a result of the particles creating routes or cavities to generate added nanometric roughness for the acid activity to be facilitated on the Ti surface.

Interesting metal ridges with small holes and irregularities (Figure 4) were visible on the surfaces of the alumina-blasted/HCl-etched surfaces, which may be explained by the ability of the quick acid to remove the majority of the alumina material used in blasting.

In the present study, the results showed three implant surface modifications with a Ra value at 1.63, 1.39, and 2.30 µm for groups A, B, and C respectively. The profilometry results revealed that sandblasting and sandblasting with acid-etching (SLActive) treatment maintained the macro-roughness value of the Ti-implant surface within the required range of 1.0-2.0 µm (moderate rough). In addition, data revealed a high Ra value for the SLActive implant which was statistically significant (Table 3), while they showed a higher rough value related to a laser implant surface treatment protocol among the test samples as shown in Table 2.

For osteoblast adhesion and differentiation during the initial stages of osseointegration as well as for long-term bone remodeling, the surface topography of dental implant is essential.[21] The topography of dental implants can be divided into macro, micro, and nanoscale levels. The visible geometry of an implant, such as threads and a tapering shape, determines its microtopography.

Alumina is the most frequently used particle for sandblasting because of its low cost, high hardness, and excellent needle form. The microscopic examination of the surfaces revealed that following sandblasting, grain boundaries vanished (Figure 3B), which was likely caused by stress-related diffusion along grain boundaries.[22,23] Most abrasive particles possessed sharp, grit forms rather than spherical shapes (Figure 3A). As a result of being blasted, some particles may become retained and contaminate the implant surface, which needs to be carefully cleaned using acid etching. The most superficial layers of the implant surface are removed by reducing surface tension and clearing the surface of any residual particles.

As a result, this study focused on employing an Er,Cr:YSGG laser to modify the Ti implant surface. This laser can produce complex surface geometries and biomedical implant surfaces since it can quickly manufacture high-resolution complex microstructures with free contamination at the nano- and micrometer scales.[24]

It was observed that the topography of the threaded implant differs considerably from the topography of Ti discs, and it is thought that the geometry of the implant influences the surface treatment. However, the majority of currently used dental implants are threaded screw types, making it challenging to analyze this type of geometry using physical or mechanical approaches.[25] By having threads with top, flank, and deep valleys, it is difficult to evaluate the topography of the screw-type dental implants by using traditional mechanical contact profilometers. The measurement inaccuracies result from the limited vertical movement of the tip and tip radius of the probe, and the surface roughness may be overestimated.[26]

Numerous manufacturers and research studies in the literature used flat Ti discs with the same surface treatment as the implants to simplify the methodological procedures. It is questionable whether the outcomes acquired by this methodology represent similar data of the threaded implant.

The current study suggests a method to modify the implant at an inclined angle by laser ablation modification of the implant surface with an internal angle of less than 45º. It is possible to confirm that the flank topography details are revealed during the flank measurement by putting the implant at an inclined angle with respect to the measurement table. Additionally, when the implant is measured perpendicular to the measuring axis, the top of the implant thread resembles the valley thread. This seems sensible because the implant surface is parallel to these small analyzed areas.

In the present study, 40% water and 50% air spray were used during laser surface treatment, which means the treatment was done under wet conditions. The radiation treatment of Ti results in the creation of sizable craters after a few pulses; this property improves the potential for the bio-integration of Ti implants (Figure 6).

A liquid medium is a preferable option for laser surface treatment because it produces better surface roughness, according to Trtica et al analysis.[27]

Utilizing a laser surface modification with a 2.5 W power protocol did not damage the surfaces of Ti implants, and it enhanced the surface roughness. Depending on the characteristics of the laser radiation source, thermodynamic characteristics of the target, the focusing technique, optical, the type and pressure of the surrounding atmosphere, laser radiation interacts with metallic targets in a variety of ways.[28] In laser modification, the Ti-based implant surface is melted or vaporized using the thermal and photonic effects of the laser to modify the chemistry and texture of the surface.[29] Dental implants with roughened surfaces have their surface qualities changed by lasers depending on pulse energy and power density.[30]

No constant protocol has been recommended for the laser Ti implant surface modification including the frequency, laser power, distance, and application time of lasers. Studies evaluated several laser settings used to irradiate dental implants using the Er,Cr: YSGG laser to see which application caused the least surface damage to the implants.[31,32]

In 2012, Park et al used the Er,Cr:YSGG lasers at 1, 2, 3, 4, and 5 W to examine machined Ti and anodized discs. When the power was greater than 3 W, both Ti surfaces showed clear modifications. [16] A study by Strever et al aimed to produce a lab-model implant that could be exposed to Er,Cr:YSGG laser irradiation at 0 W, 0.5 W, 1.0 W, and 1.5 W power with a radial firing tip without producing implant surface damage.[33]

According to a study by Alagl et al, the implant surface was modified and decontaminated with the Er,Cr:YSGG laser at 1-W power for 30 seconds without damaging the surface topography.[34] According to Chegeni et al, an Er,Cr:YSGG laser operating at 50 mJ (1.5 W/30 Hz) with side-firing and conical tips, 50% air, and 40% water for 60 s does not appear to modify the surface of implants. When the energy per pulse is increased to 84 mJ (2.5 W/30 Hz), more damage is anticipated, especially when conical tips are utilized.[17] According to research conducted by Moeintaghavi et al, the use of Er,Cr:YSGG lasers at 200 mJ/20 Hz, 2780 nm for 10s considerably damaged and changed the mean profile area between the thread implant groups.[35] On the other hand, Lin et al established a procedure for the appropriate power output setting for an Er,Cr:YSGG laser depending on the implant morphological modifications and surface roughness. They revealed that the use of 1 W or more may cause Ti surface damage and the laser should be set at 0.5 W power or less on the panel energy with water spray at 20 Hz.[36] Khalil and Sakr explained that the application of Er,Cr:YSGG (650-nm) for 60 seconds to an implant that had been grit-blasted and acid-etched caused the surface roughness to increase up to 1 μm. In addition, the number of micropores increased while showing no signs of surface melting as observed under SEM.[37]

Regarding normal bone metabolism, the Ti oxide layer on the implant surface is adjusted by laser treatment to prevent the release of ions or molecules from the Ti surface and to protect the biological environment from the extremely reactive Ti metal. This plays a major role as a diffusion barrier in the success of osseointegration and manages bone ingrowth direction.[38]

Additionally, the oxide coating has the effect of passivating the metal after laser therapy, which reduces the release of Ti ions, inhibits corrosion, influences osteoconductive behavior, facilitates tissue bonding, and provides a contaminant-free surface that can effectively improve biocompatibility.[39-41]

Erbium lasers are used in dentistry, yet there are a lot of misconceptions and misunderstandings in the dental laser market. Erbium lasers have succeeded in achieving their original goal, which was to supplement and enhance the shortcomings of the traditional mechanical tools in the dental office. However, compared to more available and widely accessible conventional methods, certain commercial interferometers have the restriction of using the Er,Cr:YSGG laser in dental clinics and are not always employed to modify implant surfaces.

The EDS microanalysis was considered a non-destructive technique because the CP-Ti G4 implant before analysis is not different from the implant after analysis. Accuracy is affected by the calculated concentrations of the individual elements within the sample and it converts the spectrum measurement results to a percentage of 100% of the entire composition.

Oxygen, nitrogen, and carbon are frequently found on Ti implant surfaces. However, Ti quickly absorbs and reacts with elements in the atmosphere, such as C, O, and N. The Ti surface forms a thin layer of amorphous oxide (TiO2) as a result of oxygen binding to it. The oxygen was visible because, in addition to being present in the atmosphere, it was also a component of the metallic oxides used in the majority of the implant systems tested during the sandblasting processes.[42]

In the Al_2O_3 blasted implant surface, relatively Ti, O, Al, and C emissions are visible. These elements are about 2%-10% of the host Ti implant. The quite large Al contamination originated from the sandblasting process, and the remaining elements appeared in the analysis due to these elements within the blasting powder (Figure 5). Furthermore, due to the cleansing procedure developed by the manufacturer, these contaminants from the manufacturing or packaging procedures may continue to be on the implant.[43]

Although the contaminated elements are not entirely removed, laser surface treatment reduces their presence. With longer time laser treatment, the contaminants may be entirely eliminated. The analysis of the surface composition following laser irradiation of the Ti implant surface showed that the proportion of O increased (Table 1). It appears that oxidation is what is changing Ti surfaces when they are exposed to laser irradiation.[16]

The current study has clinical relevance because it demonstrates that the topographical characteristics of the implant surface are essential for a successful osseointegration process. However, depending on the technique used for surface modification, residues of elements, metals, or ions may appear on the implant surface, endangering the health of the peri-implant hard and soft tissues and accelerating the development of peri-implantitis. The limitation of the current study was the lack of evaluation of various Er,Cr:YSGG laser powers and frequency settings. Additional research is necessary to determine the impact of different Er,Cr:YSGG laser settings on implant surface modifications.

Conclusion

Within the limitations of the current study, the SEM analysis showed a significant modification in implant surface topographies. The observations for the SEM-EDS analysis revealed several elements with different concentrations and a similar native oxide layer covering the modified implant surfaces of the tested groups. Compared to sandblasting and sandblasting with acid etching, the Er,Cr:YSGG laser surface modification increased the implant surface roughness value represented by thin Ti crests and smooth plates with numerous pores and raised margins that resembled volcanoes. There was an increase in the surface roughness of the Ti G4 sandblasted with Al_2O_3 particles with irregular cavities alternated with peaks and valleys in a symmetrical pattern. In contrast, sandblasted surfaces with acid etching had a microstructure that was irregularly sharp and pointed with long ridges and V-shaped valleys.

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Authors' Contribution

Conceptualization: Mohammed A Abdulla, Radhwan H Hasan, Osama Hazim Al-Hyani.
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Investigation: Mohammed A Abdulla.
Methodology: Mohammed A Abdulla, Radhwan H Hasan, Osama Hazim Al-Hyani.
Project administration: Mohammed A Abdulla, Radhwan H Hasan, Osama Hazim Al-Hyani.
Resources: Mohammed A Abdulla.
Software: Mohammed A Abdulla.
Supervision: Radhwan H Hasan, Osama Hazim Al-Hyani.
Validation: Radhwan H Hasan, Osama Hazim Al-Hyani.
Visualization: Mohammed A Abdulla, Radhwan H Hasan.
Writing–original draft: Mohammed A Abdulla.
Writing–review editing: Radhwan H Hasan, Osama Hazim Al-Hyani.

Competing Interests

The authors declare no conflict of interest.

Ethical Approval

The Ethical Committee Research, College of Dentistry, University of Mosul, REC reference (UoM. Dent/A.67/22) authorized the current study.

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