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Research Article

Effects of Diode, CO_2, Er : YAG, and Er and Cr : YSGG on Titanium Implant Surfaces by Scanning Electron Microscopy

Amir Moeintaghavi,[1] Hossein Bagheri,[2] Mahdie Yavari Pour,[3] Shervin Shafiei,[4] Hamidreza Moslemi,[4] Kamyar Abbasi,[5] Behrad Rahbani Nobar,[6] Amirreza Mehdizadeh,[3] Farzaneh Ahrari,[1] and Mostafa Alam[4]

[1]*Dental Research Center, School of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran*
[2]*Dental Materials Research Center, School of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran*
[3]*Department of Oral and Maxillofacial Radiology, School of Dentistry, Islamic Azad University, Tehran, Iran*
[4]*Department of Oral and Maxillofacial Surgery, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[5]*Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran*
[6]*Private Practice, Tehran, Iran*

Correspondence should be addressed to Mostafa Alam; mostafa_alam1@yahoo.com

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This study aimed to determine the effects of various lasers on dental implants' surface characteristics. Nine explanted dental implants were included. Two implants were randomly allocated to four intervention groups, namely, diode (2 W, 810 nm, 10 s), CO_2 (2 W, 10600 nm, 10 s), Er : YAG (200 mJ/20 Hz, 2940 nm, 10 s), and Er, Cr : YSGG (200 mJ/20 Hz, 2780 nm, 10 s) groups and one control group. After laser irradiation, all implants were imaged with scanning electron microscopy. Qualitative changes on the surface of implants were evaluated. Quantitative surface changes at the threads and between the threads were assessed by software using depression and prominence plots. The paired t-test was used for statistical analysis. Diode laser irradiation showed the least surface changes while the Er : YAG group showed the greatest surface changes. Furthermore, CO_2 and Er : YAG laser irradiation significantly altered the mean profile area at the threads ($p < 0.05$), while CO_2 and Er, Cr : YSGG laser irradiation significantly altered the mean profile area between the threads ($p < 0.05$). Diode laser irradiation does not alter the implant surface characteristics. However, the use of CO2, Er : YAG, and Er, Cr : YSGG lasers on titanium implant surfaces is discouraged as they damage the titanium implant surfaces.

1. Introduction

Peri-implantitis is defined as the inflammation of the tissues surrounding the dental implant, including soft tissues and bone, which results in progressive peri-implant bone loss [1]. It has been reported that this condition may affect 8–25% of the population which may subsequently lead to the intentional explanation of 10% of the implants [2–7]. Various nonsurgical and surgical treatment methods have been proposed for peri-implantitis treatment. However, due to differences in study designs such as patient criteria, length of follow-up, disease severity in the studied groups [8], lack of high-quality evidence [9], and long-term randomized controlled trials [10], no specific therapy has ever been described as the most effective for this condition. Recently, laser therapy has shown promising results in reducing peri-implant inflammation compared to other nonsurgical methods [11].

The aim of therapy for peri-implantitis is complete and thorough removal of microbial biofilm and calculus from the implant surface and the inner pocket epithelium. Besides, modern dental implants possess numerous morphological and topographical characteristics which can complicate complete surface detoxification by conventional methods [12–17]. Also, conventional nonsurgical therapy may also damage the implant surface [18, 19] which can further complicate subsequent epithelial attachment and may also lead to increased bacterial aggregation [20–25]. Laser therapy, with its bactericidal action, may well enhance debridement and may also prevent implant surface alteration due to its selective action [26]. However, the effects of various laser types and settings on implant surface topography have also been controversial.

While the literature supports the use of diode [27, 28] and CO_2 [28, 29] lasers on implant surface without significant topographical compromise, conflicting results have been obtained for Er : YAG(12, 28, 30) and Nd : YAG [27, 29] lasers. Additionally, to the best of our knowledge, we only found one study which had described the effects of Er, Cr : YSGG laser on implant surfaces [30]. While the conflicting results may be attributed to different implant systems used, laser energy settings, in vivo or in vitro laser applications, overall different study designs, and direct comparisons of the aforementioned lasers in identical settings are scarce throughout the literature [31]. Additionally, recent reviews on the effects of various lasers on implant surface decontamination have been inconclusive [31, 32]. Thus, in order to determine which laser type can better preserve the surface characteristics of dental implants, we aimed to investigate the effects of diode, CO_2, Er : YAG, and Er, Cr : YSGG lasers on the surface topography of dental implants via an ex vivo experimental study.

2. Materials and Methods

2.1. Design the Experimental. In this ex vivo experimental study, nine explanted titanium dental implants (Biohorizons®, Birmingham, AL, USA) with surfaces prepared with resorbable blasting media (RBM) and possessed Laser-Lok microchannels which had failed due to peri-implantitis were included. Peri-implantitis was diagnosed by observing recurrent gingival bleeding from the affected site, bleeding on probing, suppuration, and increasing pocket depth since insertion [33]. This diagnosis was also confirmed by radiographic examination by observing bone loss around the implant shoulder and the presence of radiolucencies around the implant. All dental implants were previously inserted by one surgeon. For explantation procedures, the same surgeon used the method described by Shibli et al. [34] which consisted of the removal of the implants under local anesthesia. Steel forceps were used to grab the implants by the cover screw and remove them from the bone. Subsequently, each implant was copiously irrigated with saline solution (DarouPakhsh Pharmaceutical, Tehran, Iran) until no visible organic remnants such as blood or saliva remained on the implant surface. Additionally, titanium tweezers were used to remove any possible soft tissue remnants on the implant surface. Thereafter, each implant was placed in a separate previously sterilized plastic bag. Based on the acquired data from the pilot study, a number of two implants per group would be necessary in order to conduct statistical analysis as later described in this section. Out of nine implants, eight of them were allocated to four groups, namely, diode, CO_2, Er : YAG, and Er, Cr : YSGG groups. The one remaining implant was determined as the control group. Sample size calculation was based on a pilot study which had been conducted before the actual study was conducted. The aim and design of the study and the surgical procedure were thoroughly explained to patients, and a written informed consent was obtained from all participants.

2.2. Preparing the Groups. In order to prepare the samples for laser treatment, every implant's surface was painted with an oil ink while leaving two 4×3 mm rectangular windows on the implant surface unpainted. The windows on all implants began from the second thread and ended on the sixth thread. One of the windows would serve as the laser treatment group while the other would serve as the untreated surface which was also protected by an aluminum foil covering. Each implant was carefully handled in this process so as not to contaminate the implant surface. Subsequently, each implant was mounted on an acrylic resin jig for subsequent procedures. The implants were randomly allocated to five groups which consisted of four intervention groups and one control group. Each group received different laser treatments.

In the first group, the specified window was irradiated using diode laser (2W, 810 nm) (FOX IV, A.R.C Laser, Nuremberg, Germany) using a 400 μm sized tip with a sweeping motion in a continuous wave [35] mode from a one-millimeter distance with a 90-degree angulation with the implant surface for 10 seconds.

In the second group, the specified window was irradiated using CO_2 laser (2W, 10600 nm) (Smart US-20, Deka, Florence, Italy) using a 400 μm-sized tip with a sweeping motion in the CW mode from a one-millimeter distance with a 90-degree angulation with the implant surface for 10 seconds.

In the third group, the specified window was irradiated using Er : YAG laser (200 mJ/20 Hz, 2940 nm) (Key3, KaVo, Biberach, Germany) using a 400 μm-sized tip with a sweeping motion in the pulsed mode from a one-millimeter distance with a 90-degree angulation with the implant surface for 10 seconds. The spray was set at 50% of the maximum and saline solution was used for the spray.

In the fourth group, the specified window was irradiated using Er, Cr : YSGG laser (200 mJ/20 Hz, 2780 nm) (WATERLASE IPLUS®, BIOLASE Inc., Irvine, CA, USA) using a 400 μm-sized tip with a sweeping motion in the pulsed mode from a one-millimeter distance with a 90-degree angulation with the implant surface for 10 seconds. The spray was set at 50% of the maximum, and saline solution was used for the spray.

The fifth group served as the control group. No laser interventions were conducted on this group so as to exclude any irradiation effects such as transmission.

2.3. Scanning Electron Microscope (SEM) Analysis. The specimens were subsequently prepared for scanning electron microscope (SEM) evaluation. Firstly, the specimens were fixed in 2% paraformaldehyde solution (Sorenchem, Mashhad, Iran) and then subjected to progressive dehydration in increasing concentrations of ethanol (Kimiaalcoholzanjan, Tehran, Iran). Then, the specimens were sputter-coated with a 50 nm layer of gold due to the higher backscattering coefficient of gold than other elements which prevents microscope beam damage. This thin layer of gold does not alter the topographical characteristics of the specimens. Thereafter, the specimens were placed in a vacuum container and SEM images were subsequently obtained (SEM; S-4700, Hitachi, Japan). The SEM images were qualitatively evaluated for signs of damage by two blinded assessors. For quantitative analyses, images with equal magnification were selected and imported into ImageJ software (National Institutes of Health, Bethesda, MD) by a blinded assessor [22, 36]. Six segments with the length of 100 pixels were drawn on the implant threads and also between the implant threads. Analyses of the surface characteristics at the threads and between the threads were conducted separately. Subsequently, the profile area plugin was used to develop the depression and prominence plot based on the numerical value of each grey shade of every pixel. The grey values ranged from 0 to 1000, i.e., completely white pixels were assigned a value of 1000, while completely black pixels were assigned a value of 0. Subsequently, the area under the curve of each profile area was calculated and the means of all the six segments were obtained. The values obtained for each profile area was used to determine quantitative surface changes before and after laser irradiation. Analysis was carried out by one experienced oral and maxillofacial radiologist. All assessments were carried out by one experienced and blinded operator.

We used the paired t-test for the quantitative surface changes' analyses using a software package (SPSS 11.0, SPSS Inc., and Chicago, IL, USA). A p-value of less than 0.05 was considered as statistically significant in all analyses.

3. Results

3.1. Qualitative Changes. This study was done to determine the effects of various lasers on the surface topography of titanium dental implants which were explanted because they were affected by peri-implantitis. The resultant changes could be classified as qualitative and quantitative. Figure 1 shows the SEM image of the control group (Figure 1). Figures 2–5 are the SEM images of the laser groups. The least amount of surface changes were observed in the diode laser group, while the highest amount of surface changes were observed in the Er : YAG laser group. The diode laser SEM images exhibited the least amount of surface alterations between the threads (Figure 2). Likewise, CO_2 laser irradiation melted both the threads and surfaces between the threads. Additionally, this laser also increases the surface roughness (Figure 3). It was shown that the Er : YAG laser completely alters the implant surface topography both at the thread level and between the threads (Figure 4). Er, Cr : YSGG laser irradiation increased the surface roughness both at the thread level and between the threads. Additionally, it also melted the implant surface between the threads and changes the surface topography at the thread level (Figure 5).

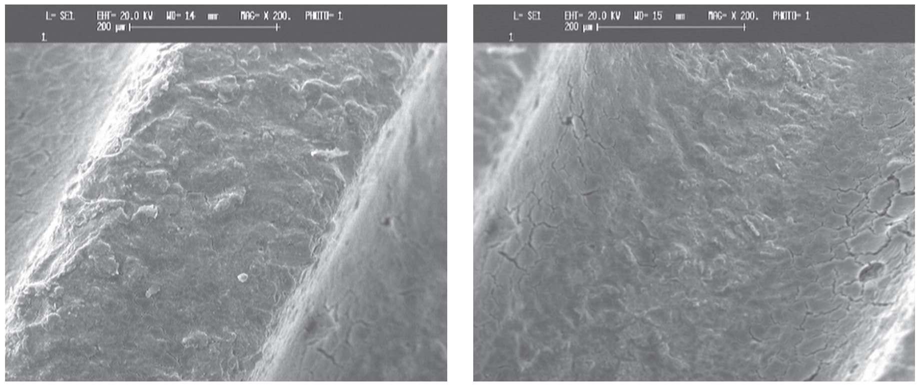
3.2. Quantitative Changes. Table 1 summarizes the mean profile area before and after laser irradiation at the thread level (Table 1). Table 2 summarizes the same values before and after laser irradiation for the surfaces located between the threads (Table 2). Er : YAG and CO_2 lasers significantly changed the mean profile area at the threads. Er, Cr : YSGG and CO_2 lasers significantly changed the mean profile area between the threads.

4. Discussion

This ex vivo experimental study aimed to evaluate the effects of various laser wavelengths' irradiation on titanium implants' surface topographies. It was found that diode laser irradiation produced the least amount of surface changes, while CO_2, Er : YAG, and Er, Cr : YSGG lasers produced significant surface alterations. As mentioned before, one of the main limitations of the previous studies on implant surface decontamination strategies has been their limited comparability. Factors such as power output, operation mode, irradiation time, and distance from the specimens, irradiation angles, specimen types, and preparation can confound the results of these strategies' comparisons [31, 34]. This study provided a setting in which the comparison of the four types of lasers became feasible.

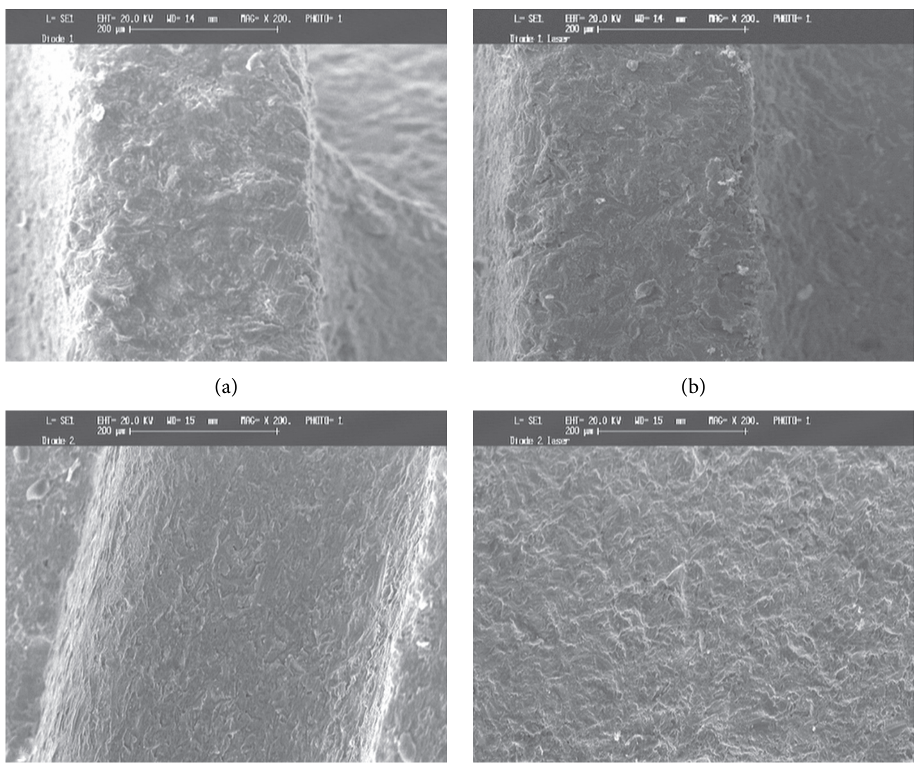
In order to replicate the clinical situation as much as possible, we used explanted implants from human subjects as opposed to titanium disks [27, 28, 30, 35] or unused implants [37–39]. This approach helps simulate the clinical situation as much as possible where the chemical composition of the implant surface may be altered due to deposition of human or bacterial remnants which may alter the titanium dissolution rate due to blockage of oxygen cathodic reaction [34]. Furthermore, the power settings for each of the lasers used were based on the works of previous studies with regards to temperature elevations due to laser irradiation so that the results of our study would not be confounded by excessive temperature rises, i.e., more than 10 degrees Celsius [40] within the specimens [27, 35, 38]. Thus, excessive temperature increases in the implant body was ruled out as a confounding factor.

According to the qualitative and quantitative results, the Er : YAG and Er, Cr : YSGG groups demonstrated significant surface alterations which are also in line with the results of previous studies [28, 38, 39]. These alterations may be due to microexplosions associated with the effect of these lasers on the water which was sprayed during irrigation, thus damaging the nearby surface in addition to irradiation



(a) (b)

Figure 1: Scanning electron micrograph of the control group. (a) Thread surface (×200). (b) Between thread surfaces (×200).



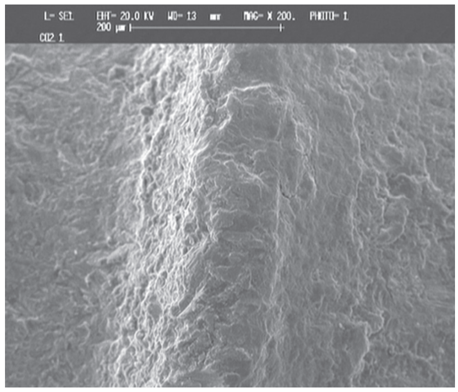
(a) (b) (c) (d)

Figure 2: SEM image of the diode laser group. (a) Thread surface before laser irradiation (×200). (b) Thread surface after laser irradiation (×200). (c) Between thread surfaces before laser irradiation (×200). (d) Between thread surfaces after laser irradiation (×200).

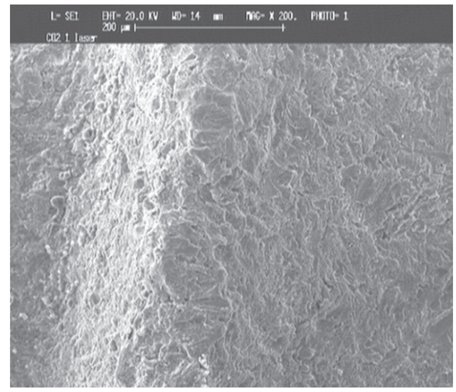
absorption at the implant surface. Additionally, CO_2 laser application also altered the implant surfaces. We only found one study which supported our results about CO_2 irradiation-related damage [41]. The diode laser did not show any significant surface changes. This finding was also in line with the results of the previous studies [27, 28, 42].

It has been stated in the literature that, due to the higher spectral reflectance values of titanium for lower wavelengths, lasers with longer wavelengths can produce lesser damage, while lasers with shorter wavelengths can produce more damage [43]. Although CO_2 laser damage was lower compared to Er : YAG laser, it still did inflict significant damage to the implant surface. This shows that although CO_2 laser irradiation is reflected off the implant surface to a higher degree, surface alterations by CO_2 laser irradiation are still possible. As previously stated, the chemical composition of the implant surface might have been altered. Thus, CO_2 laser irradiation might not have been so readily reflected as previously thought.

Inevitably, this study also had some limitations. In order to minimize the confounding effects of beam angulation on the amount of energy transfer to the specimens, we opted for an



(a)



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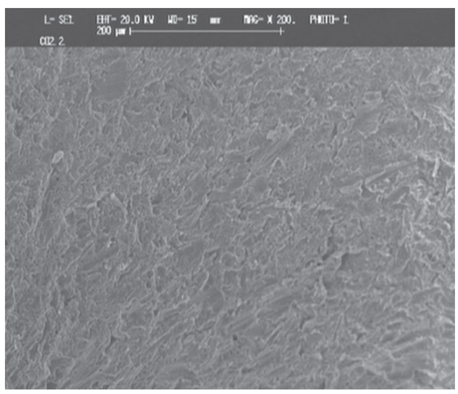
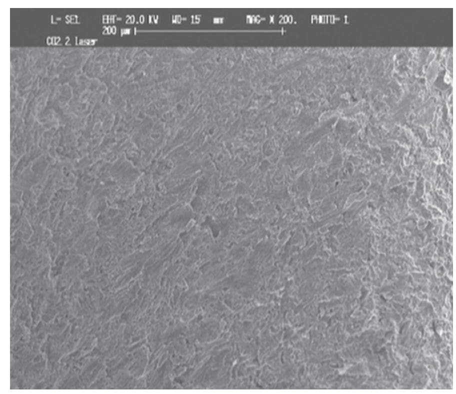
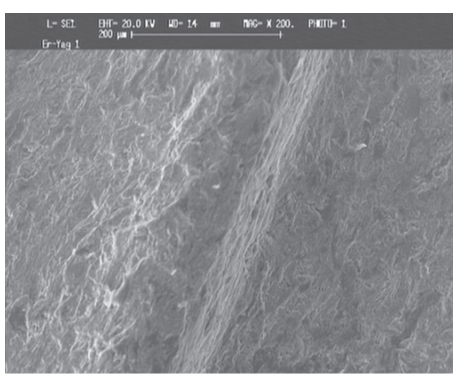


(c)

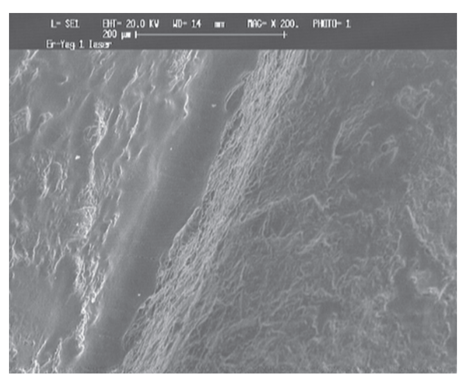


(d)

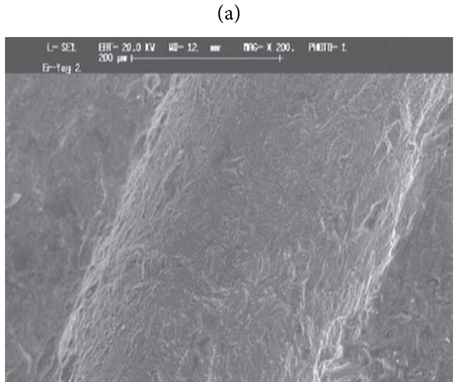
Figure 3: SEM image of the CO_2 laser group. (a) Thread surface before laser irradiation (×200). (b) Thread surface after laser irradiation (×200). (c) Between thread surfaces before laser irradiation (×200). (d) Between thread surfaces after laser irradiation (×200).



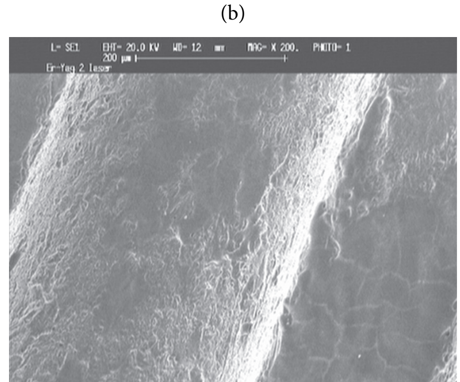
(a)



(b)



(c)



(D)

Figure 4: SEM image of the Er : YAG laser group. (a) Thread surface before laser irradiation (×200). (b) Thread surface after laser irradiation (×200). (c) Between thread surfaces before laser irradiation (×200). (D) Between thread surfaces after laser irradiation (×200).

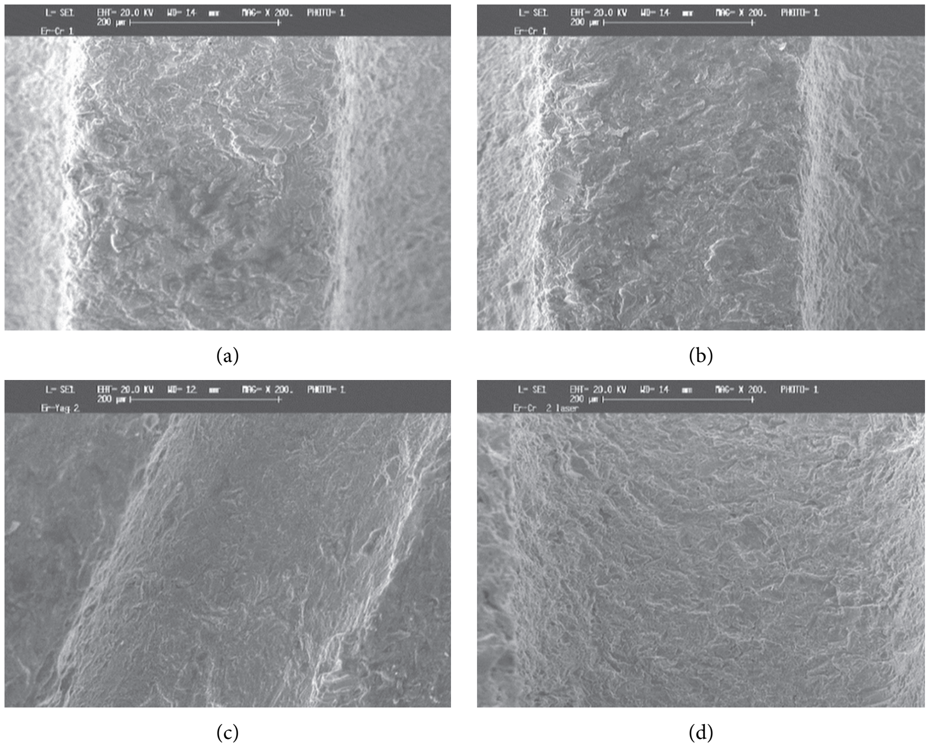


Figure 5: SEM image of the Er, Cr : YSGG laser group. (a) Thread surface before laser irradiation (×200). (b) Thread surface after laser irradiation (×200). (c) Between thread surfaces before laser irradiation (×200). (d) Between thread surfaces after laser irradiation (×200).

Table 1: Mean profile area before and after laser irradiation at the thread level.

Laser type	Mean profile area before laser irradiation	Mean profile area after laser irradiation	p value
Diode	3749/20 ± 840/36	3196/96 ± 450/59	0.186
CO_2	2802/47 ± 328/55	4832/45 ± 1095/37	0.001
Er : YAG	2495/75 ± 522/48	920/73 ± 189/27	$p < 0.001$
Er,Cr : YSGG	2842/93 ± 579/52	3342/10 ± 1314/93	0.415

Table 2: Mean profile area before and after laser irradiation between threads.

Laser type	Mean profile area before laser irradiation	Mean profile area after laser irradiation	p value
Diode	3154/24 ± 620/93	3226/47 ± 378/21	0.813
CO_2	2227/90 ± 484/65	3673/34 ± 1241/76	0.024
Er : YAG	2431/21 ± 475/10	3072/03 ± 565/78	0.060
Er,Cr : YSGG	5089/38 ± 1627/58	4493/25 ± 679/92	0.042

approximate 90-degree angle of irradiation in all intervention groups using a free-hand technique. This angulation can readily be achieved in clinical situations such as open flap debridement but may not be possible when conducting nonsurgical periodontal therapy. Nonsurgical therapy may require a more parallel irradiation angle, the effects of which should be investigated in future studies. Furthermore, successful implant surface decontamination must also ensure suitable chemical composition and biocompatibility of the irradiated surface which should also be evaluated in future studies.

5. Conclusions

Diode laser irradiation does not change the implant surface characteristics and can therefore be a safe option for implant surface decontamination. However, the use of CO_2, Er : YAG, and Er, Cr : YSGG lasers can damage the surface properties of titanium implants, and therefore, they should be used with caution. Moreover, further studies regarding different lasers' setting and other confounding factors are suggested by this article.

Data Availability

The data used to support the findings of the research are available from the corresponding author upon reasonable request.

Ethical Approval

Considering the ex vivo design of this study, no ethical objections to the design and process of this study were made at the time of conducting this research.

Conflicts of Interest

The authors have no conflicts of interest.

Acknowledgments

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