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Comparative Scanning Electron Microscopic Evaluation of diode lasers and Er,Cr:YSGG Laser Irradiation effect on bio-tribocorrosion of Retrieved Failed titanium Dental Implants: An In Vitro Study

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Abstract

Purpose

This in vitro study aimed to comparatively evaluate the effects of Er,Cr:YSGG (2780 nm) and diode (810 nm) laser irradiation on the surface morphology and integrity of retrieved failed dental implants exhibiting corrosion-related alterations, using scanning electron microscopy (SEM).

Methods

Five failed implants were collected from patients with peri-implantitis. The collected implants were divided into three groups. For the first group (G1), one implant was considered as a control without any laser irradiation. The remaining four implants were divided into 2 implants irradiated by Er,Cr:YSGG 2780 nm (G2) and 2 implants lased by diode 810 nm laser (G3). Examination using a scanning electron microscope was done after laser application to detect surface changes on implant surfaces.

Results

Er,Cr:YSGG 2780 nm laser resulted in a homogeneous implant surface while the diode 810 nm laser did not cause any surface alterations but was absorbed by the bacterial colonies found on the corroded implant surfaces.

Conclusion

Er,Cr:YSGG 2780 nm laser has a positive effect on the corroded implant surface, by making its surface nearly like that of a new implant. The diode 810 nm laser has a bactericidal effect on implants' surface colonising bacteria but did not cause changes in the implants' surface morphology.

Introduction

Titanium (Ti) and its alloys are often used in dental implants because they are biocompatible, resistant to corrosion, and have good mechanical properties. In fact, tribocorrosion is an irreversible process of material degradation because of the mixed action of wear (tribo), and the hostile environment (corrosion) which induce each other simultaneously [1]. Over the decades, dental implant failure has been attributed to peri-implant diseases. Nevertheless, bio-tribocorrosion is considered another substantial cause of implant failure, as the wear, cracks, and released particles and ions from Ti-based implant [2] can trigger foreign-body reaction, resulting in increased peri-implant infection and bone loss. [3]

Bio-tribocorrosion can take place due to various factors, which can be mainly categorised as implant-related (mechanical) factors, and oral environment-related (bio-chemical) factors. First, friction caused by insertion torque, loading, and implant placement, together with physiological cyclic stresses (250–450 N), can cause micromovements between the implant and abutment, or the abutment and the prosthetic crown, during function. This leads to the development of micro-gaps [4–6]. These micro-gaps intensify the corrosive process by increasing saliva and oral biofilm contact with implant surfaces [7]. The structural material, connection design, and surface treatments of implant systems are further mechanical variables that affect the bio-tribocorrosion damages [8, 9].

One of the essential causes of bio-tribocorrosion is the “oral environment-related (biochemical) factors. An important variable, which has significant impact on bio-tribocorrosion, is the pH of the saliva. Normally, the pH of the saliva ranges from 6.2 to 7.4 (neutral pH) and varies from patient to patient. The pH of the saliva changes chemically depending on human habits, which can influence the implant surface characteristics [10, 11]. Ti degradation can also be impacted by chronic illnesses, drugs, infection processes and smoking products [12] Similarly, oral mouthwashes degrade the surface of metallic biomaterials [13]. The amount of fluoride used in regular toothpaste might also have a negative impact on titanium alloys' active dissolution and tribocorrosion resistance [14, 15].

The oral cavity is full of microorganisms which negatively affect the titanium oxide layer of the implant body when surrounded by peri-implantitis [16]. Oral fluids and biofilms in the implant's internal connection and micro-gaps may be one of the causes of abutments unscrewing; this results in extremely low friction on Ti under sliding [14]. Overall, the increased surface roughness caused by microbial attachment, inflammatory response products, and Ti's higher susceptibility to corrosion from bacteria can all have an impact on the material's bio-tribocorrosion. Notably, corrosion can be limited by passivation, in which a protective oxide layer called a “tribolayer” created by the physicochemical interactions of surfaces and the mutual transfer of components [16]. However, this tribolayer is often subjected to damage by tribocorrosion phenomena since its implantation, and during its lifetime of service, as different contact conditions can cause varied stability and disintegration of tribolayers [17, 18].

In order to prevent tribocorrosion damage and to minimise the amount of bone tissue loss around dental implants, it is essential to regulate oral biofilm formation [7]. Additionally, the application of lasers could be a successful strategy to counteract bio-tribocorrosion. However, the use of lasers can significantly affect the morphology of an implant surface. Therefore, before this treatment option can be successfully implemented in a clinical setting, it is vital to investigate the effect of laser irradiation on corroded implant surfaces [19]. Er,Cr:YSGG (2780 nm) and photosensitizer-assisted diode (810 nm) lasers were selected to decontaminate through different mechanisms: photomechanical ablation and photodynamic action, respectively. [20, 21] Comparing them allows evaluation of how each affects the morphology of corroded implant surfaces under scanning electron microscope (SEM). Giving the existing gap in knowledge, the purpose of this study is to examine and compare under SEM, the effect of Er,Cr:YSGG (2780 nm) and Diode (810 nm) laser irradiation on the corroded parts of failed implants.

Materials and Methods

Study Design

An in vitro experimental study was conducted to evaluate the effects of two laser systems, Er,Cr:YSGG (2780 nm) and diode (810 nm), on corroded dental implant surfaces using SEM. The study was conducted at a private dental clinic (Dental Care Center, DCC, Cairo, Egypt). The study protocol was reviewed and approved by the Misr International University Institutional Review Board (MIU-IRB) (Approval No. MIU-IRB-2324-025) and classified as non-human subjects.

Samples Preparation

Five failed dental implants (Zimmer, USA; BioHorizons, Henry Schein, Inc., Alabama, USA; INKONE, Tekka, Lyon, France; and Vitronex, Italy) were collected from both genders, with an age range 35–50 years old, whose implants had been scheduled for replacement due to peri-implantitis

Written informed consent was obtained from all patients for the use of their retrieved failed implants in the present study. Retrieved failed implants were then stored in saline solution at room temperature until examination. Initially, all five implants were evaluated and scanned under a scanning electron microscope (SEM) to determine which area would be tested. The selected areas were marked by a coloured varnish (Luna, Cairo, Egypt) to facilitate after testing re-evaluation. Following Taniguchi et al. [22] protocol, failed implants were embedded into a mould with one exposed surface; simulating the bone loss that occurs in clinical cases of peri-implantitis. The five implants were divided into three groups according to the assigned treatment protocol: one implant served as the untreated control group (G1), two implants were irradiated using an Er,Cr laser (2780 nm) (G2), and the remaining two implants were irradiated using a diode laser (810 nm) (G3).

Laser Application

For the control group (G1, n = 1), one retrieved failed dental implant was left untreated and served as the control, without exposure to laser irradiation.

For Er,Cr:YSGG group (G2, n = 2), 2780 nm laser beam was emitted using a gold handpiece of radial firing periodontal tip (RFPT5), 500 μm Fiber diameter and 14 mm in length, with a 2W average power, 40 mJ/s pulse energy, 50 Hz repetition rate, 60 μs pulse duration with 20% air and 60% water settings. Laser irradiation was applied over the entire exposed implant surface using a sweeping motion, while maintaining a 2 mm distance between the tip and the treated surface.

For the diode laser group (G3, n = 2), the implants were immersed in methylene blue dye for 30 seconds and then rinsed with saline solution. Methylene blue was selected due to its established application as a photosensitizing agent in antimicrobial photodynamic therapy (aPDT), where light activation at an

appropriate wavelength induces the generation of reactive oxygen species (ROS), contributing to antimicrobial effects [23, 24].

Its use in the present study aimed to investigate its potential contribution to laser-mediated surface treatment. Diode laser irradiation was subsequently performed using an 810 nm diode laser at an output power of 1 W, equipped with a 400 μm non-initiated fiber tip. Irradiation was applied for 30 seconds using a sweeping motion while maintaining a 2 mm distance between the tip and the implant surface.

Scanning Electron Microscope (SEM) Surface Analysis

Each implant mould was mounted to the SEM in which the implant's desired area was kept exposed for examination. The implant cervical area marked with colored varnish before laser irradiation was used as reference points to relocate the previously identified areas of bio-tribocorrosion during post-treatment examination.

SEM imaging was performed at different magnifications ranging from 800× to 6000× to evaluate the morphological characteristics and surface alterations of the implant specimens following laser application Each implant was considered the experimental unit, and individual SEM images were treated as repeated observations rather than independent samples.

Results

SEM analysis

SEM images of the control implant (G1) revealed implant corrosion in the form of an eroded surface with the leach of titanium debris, pitting and cracks on the implant surface. Particulate deposits and aggregates of structures morphologically consistent with bacterial colonization were also observed, particularly within surface irregularities were also noticed in Fig. 1. However, in implants treated by Er,Cr:YSGG 2780 nm laser (G2) showed a homogenous implant surface with a significantly reduced bacterial colonisation showed in Fig. 2. As for the diode laser (810 nm) group (G3); low-energy laser was absorbed by the bacterial colonies inhabiting the corroded areas in Fig. 3. Although methylene blue was used as a photosensitizer during diode laser irradiation, the SEM findings were limited to morphological observations and could not directly demonstrate photosensitizer activation, laser energy absorption, or bacterial viability. Accordingly, the null hypothesis was not rejected, as the descriptive SEM findings alone were insufficient to establish statistically significant differences in surface morphology among the examined groups.

Discussion

The present in vitro study aimed in assessing the effect of Er,Cr:YSGG 2780 nm (G2) and Diode 810 nm (G3) lasers on corroded implant surfaces, as laser treatment became an appropriate alternative to

conventional methods for the management of tribocorrosion behaviour and peri-implantitis. The results of this study highlighted that in the control implant (G1); cracked and pitted implant surfaces were observed, and titanium debris were found. This can be influenced by the bio-tribocorrosion effect on the implant surface.

On the other hand, SEM examination of the Er,Cr:YSGG 2780 nm group (G2) revealed relatively more uniform surface regions compared with the untreated control. However, localized surface irregularities remained evident, and the absence of a pristine implant reference and pre-treatment assessment limits any conclusion regarding restoration of the original implant surface characteristics.

However, the diode laser at 810 nm (G3), did not show any surface alterations. A possible explanation could be due to its absorption only in melanin (pigments) and haemoglobin. Moreover, the bacterial colonies inhabiting the corroded implant surface absorbed laser irradiation, which was noticed by using a methylene blue stain. It is worth mentioning that methylene blue dye was considered the best chromophore to be absorbed by the low-energy lasers [25]. Thus, diode lasers at 810 nm (G3) might have an influential bactericidal effect, and the incidence of peri-implantitis might be reduced by their use, which in turn decreases the possibility of bio-tribocorrosion activity.

One of the consequences of bio-tribocorrosion is material wear, which may result in the release of titanium and other metallic particles from the implant surface. This phenomenon was evident in the untreated control group of the present study, as showed in Fig. 1. These findings are consistent with a previous clinical investigation in which soft and hard tissue biopsies obtained from patients with severe peri-implantitis were examined for the presence of metallic wear debris. Titanium particles were identified in 75% of the investigated samples. Their presence was suggested to be associated, at least partly, with micromovement between the implant and abutment during cyclic loading. Additionally, the existence of micro-gaps between the implant and its abutment might allow the seepage of wear debris into the peri-implant tissues [5, 26]

Similarly, the findings of the present study were consistent with those of Moeintaghavi et al. [27], who reported surface alterations following Er,Cr:YSGG 2780 nm laser (G2). These changes were attributed to laser-induced micro-explosions resulting from interaction with irrigation water. However, increased surface roughness at thread level and between threads as well as melting were also reported, potentially due to the higher pulse energy (200 mJ/pulse) compared with that used in the present study (40 mJ/pulse), highlighting the influence of laser parameters on implant surface morphology.

In contrast to earlier findings, an in vitro study did not identify any surface morphological changes on the implant surface using Er,Cr:YSGG 2780 nm laser (G2). This might be attributed to the implant surface contamination without showing any erosions or actual surface changes due to the different parameters (1W, 50% water, 50% air and 30 Hz) and different laser tips [28]. Despite the success of using laser debridement of failed infected dental implants, surface alterations chemically and structurally remained questionable. Biedunkiewicz et al. compared the effect of diode laser 980 nm laser to Er,Cr:YSGG at 2780 nm laser (G2) on implants using a scanning electron microscope (SEM) equipped with the

microanalysis adapter and found no chemical or microstructural changes on the implant surfaces [29]. Implant discs exposed to an Er,Cr:YSGG at 2780 nm laser (G2) at 2W, showed no unfavourable changes such as holes, pits, voids, microfractures or inclusions [30].

In another in vitro study involving failed implants, Er,Cr:YSGG 2780 nm (G2) laser irradiation using different laser parameters resulted in surface characteristics comparable to those of the original implant surface, without evident additional alterations [31]. The differences between those findings and the observations of the present study may be related to variations in irradiation parameters, particularly the power (2 W), pulse energy (40 mJ/pulse), and frequency (50 Hz) used in the current study, despite the use of a similar laser tip (RFPT5).

The parameters used in the present study of Er,Cr:YSGG group confirmed the positive results of earlier study which applied laser on hydroxyapatite-coated or sandblasted implant surface of 2780 nm and below 100mJ/pulse for 1 minute to debride implants showing no surface alterations. However, it is worth mentioning that the type of laser handpiece tip used might influence the efficacy of laser debridement which will in turn permit bio-tribocorrosion to occur and affect the implant surface negatively [32].

Furthermore, the effectiveness of implant decontamination and calcified deposits removal using erbium lasers; Er:YAG and Er,Cr:YSGG at 40 mJ/pulse (ED 14.2 J/cm2/pulse) and 20 Hz with water spray, proved to have shown surpassing implant debridement effect compared to cotton pellets or titanium curettes and cause little damage to the surfaces [33]. Erbium lasers not only showed a bactericidal effect on microorganisms, but also have the capability of removing calculus, plaque, smear layer, and promoting fibroblast attachment [34–36]. On the contrary, another ex vivo research showed a superior effect of implantoplasty in removing bacteria from failed implants compared to other techniques including laser, chemical agents, hydrogen peroxide, and airborne-particle abrasion [37].

The use of diode laser as an adjunctive therapy in the treatment of peri-implant mucositis showed promising results, being more effective in reducing the inflammation of the peri-implant tissue, positioning itself as a valuable tool for the treatment of peri-implant pathologies [38]. Diode laser used up to 3 W was advised if the goal of decontamination is to prevent any change to the implant surface [39]. Gonçalves et al. [40] irradiated implants contaminated with *P. gingivalis* and *E. faecalis* for 5 min at 2.5 W and 3 W using a 980 nm diode laser and assessed bacterial reduction and implant surface alterations. The use of 3 W pulse energy showed 100% effectiveness for surface decontamination with no adverse effects on the treated surfaces [40].

Alternatively, lower pulse energy of 1 W, in pulsed mode, with air/water cooling, could be used without fearing the thermal effects of diode lasers (810 nm and 980 nm) in which temperature was kept below the critical threshold of 47°C. It was also successful when used as an adjunctive therapy to conventional or erbium (dual wavelength) and eliminated inhabitant bacteria and helped in the treatment of peri-implantitis [41]. Similarly, a low pulse energy 1W diode laser was used and also showed successful results in reducing bacterial colonisation [10]. The observed bacterial-associated deposits within surface

irregularities may be explained by the influence of implant surface characteristics on microbial adhesion. Al-Wattar et al. [42] emphasized that implant surface roughness, type, and design may influence bacterial colonisation and biofilm formation, highlighting the importance of preserving implant surface characteristics during decontamination procedures.

Laser induced thermal effects are of course an important consideration during implant surface decontamination as temperature rise can lead to surface changes and release of titanium particles [43, 44].The magnitude of the effect will be dependent on the laser type, the irradiation parameters and the implant surface. Hence, it is important to select appropriate laser settings to minimize the risk of thermal damage and undesirable surface modification. The use of pulsed irradiation mode, short exposure times, adequate cooling and low energy settings has been advocated to improve the surface damage [45].

Conclusion

The present study compared the effects of Er,Cr:YSGG (2780 nm) and diode (810 nm) laser irradiation on retrieved failed implant surfaces. SEM examination revealed differences in surface morphology following the two laser protocols, with relatively more uniform surface regions observed in the Er,Cr:YSGG group, whereas surface irregularities and localized deposits remained evident in the diode laser group. These findings highlight the influence of laser type and irradiation parameters on implant surface morphology. However, further studies involving larger sample sizes are required to investigate bone and soft tissue reattachment, as well as bacterial loads, implant temperature rise and their effect to the surrounding tissues.

Declarations

Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection, figures and analysis were performed by A.E. The full manuscript was written by A.E., M.A.M.T., and S.M. While M.E. contributed to the critical revision, reviewing and editing of the manuscript. A.I.A. contributed to the final review and editing of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The Datasets used in the current study are available through the corresponding author upon justifiable request.

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Figures

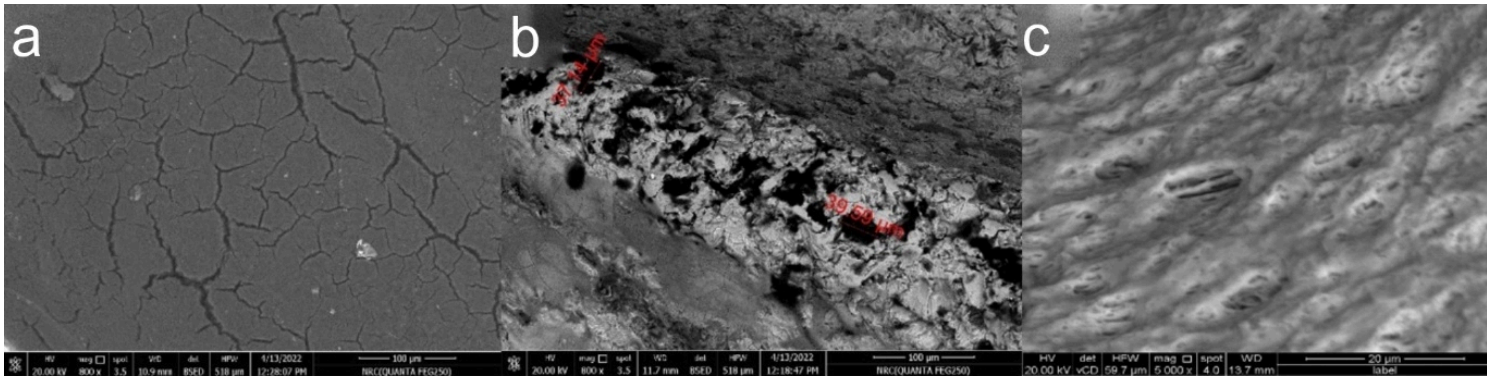

Figure 1

SEM imaging of control implant (G1); showing surface alterations caused by tribocorrosion
(a): Cracks appear on the implant surface (at 800x magnification power).
(b): Leached out titanium debris (at 800x magnification power).
(c): Pitted implant surface (at 5000x magnification power)

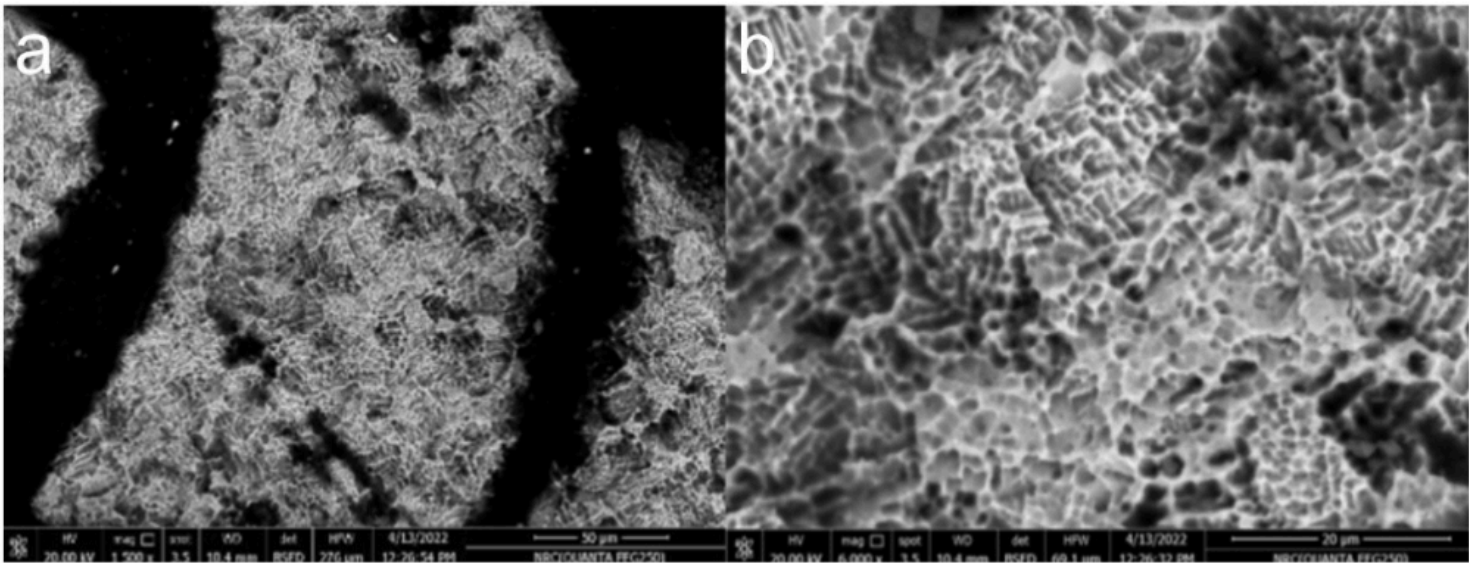

Figure 2

SEM imaging of Er,Cr:YSGG 2780 nm group (G2); showing a homogenous implant surface ((a):at 1500x and (b) at 6000x magnification power)

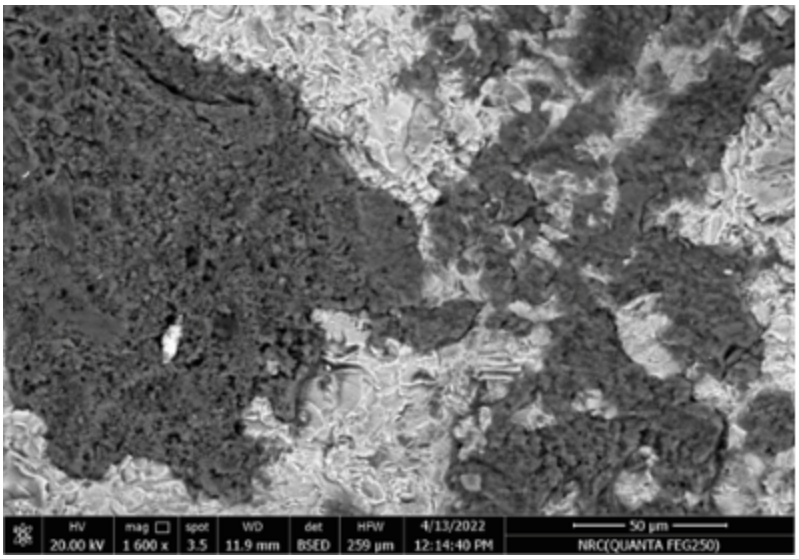

Figure 3

Implant surface treated with a diode laser (810 nm) (G3); showing staining of the bacterial colonies by methylene blue inhabiting the corroded areas and absorbing the minimal amount of the used diode laser energy (at 1600x magnification power)