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CHARACTERIZATION OF TITANIUM IMPLANT SURFACE AFTER Nd:YAG LASER TREATMENT

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ABSTRACT

CHARACTERIZATION OF TITANIUM IMPLANT SURFACE AFTER Nd:YAG LASER TREATMENT

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Introduction: Dental implants are excellent restorative solutions. They can, however, present challenging complications ranging from reversible inflammation (peri-implant mucositis) to irreversible inflammation with bone loss (peri-implantitis). Treatment modalities consist of non-surgical and surgical approaches including the use of lasers. According to the American Academy of Periodontology, evidence for laser therapy in peri-implant disease is equivocal, and there is insufficient evidence to determine the long-term impact of laser-induced implant surface alterations.

Objectives: The purpose of this *in vitro* study was to measure surface changes on titanium discs following neodymium-doped: yttrium, aluminum, and garnet (Nd:YAG) laser irradiation at four clinically relevant angles (0, 10, 20, and 30 degrees) to quantify laser surface damage, and determine if laser angulations influence the damage.

Materials and Methods: 40 titanium discs were evaluated, four test groups (n=10) with 10 randomly selected discs serving as a pre-laser control group. A customized actuator assembly exposed discs to standardized Nd:YAG laser energy at a constant speed. Confocal microscopy (Zeiss LSM 980) was used to quantify surface topography of all discs in a standardized manner.

Results: Confocal microscopy successfully provided ideal feature fidelity in small, lateral dimensions to quantify topographic values. The actuator assembly allowed a controlled and reproducible delivery of laser energy. Control disc imaging revealed microscopically irregular surfaces with an average of 16.6% local variance.

Conclusion: The orientation of the Nd:YAG fiber-optic in the peri-implant sulcus is critical. When the Nd:YAG laser interacts with titanium, inadvertent energy can impact the surface characteristics and release titanium particles into the sulcus. Further analysis is required to determine if laser-induced alterations to the implant surface negatively impact osseointegration.

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LIST OF ABBREVIATIONS

Neodymium-doped: yttrium, aluminum, and garnet - Nd:YAG

CHAPTER I: REVIEW OF THE LITERATURE

Periodontal diseases include pathologic processes affecting the periodontium and are divided into gingivitis and periodontitis. Gingivitis is a reversible inflammation of the gingival tissue. There is no destruction of the attachment apparatus that includes the periodontal ligament, cementum, and bone. In contrast, periodontitis involves inflammation of the periodontal tissues resulting in clinical attachment loss, alveolar bone loss, and periodontal pocketing. Periodontitis, especially if untreated, can lead to the progressive loss of teeth. Similar inflammatory disease processes have been noted around endosteal dental implant fixtures. Peri-implant mucositis is defined as a disease in which the presence of inflammation is confined to the mucosa surrounding a dental implant with no signs of supporting bone loss. Peri-implantitis is defined as an inflammatory process around an implant with soft tissue inflammation and loss of supporting bone[1].

According to the 2009-2014 National Health and Nutrition Examination Survey, 68.6% of participants were diagnosed with periodontitis and had a range of 6 to 27 missing teeth. One common treatment option to replace missing teeth is dental implants. Modern titanium alloy dental implant fixtures are designed to be surgically inserted into the endosteal layer of alveolar bone. The fixture acts as the foundation upon which a dental implant crown will be placed to serve a functional, therapeutic, and esthetic purpose[1]. The prevalence of dental implants placed across all age groups is 2.9%, with the highest prevalence in the 65 year or older cohort at 6.2%[2]. Although dental implants are an excellent restorative option they are not without complications. These complications can range from peri-implant mucositis, where the inflammation is confined to the surrounding soft tissue; to peri-implantitis, where the inflammation has infiltrated into the bone supporting the implant[1]. The 2008 Consensus Report of the Sixth European Workshop on Periodontology estimated that peri-implant mucositis is found in approximately 80% of subjects and 50% of implant sites. The authors also concluded that peri-implantitis is found in a range of 28-56% of subjects and at 12-40% of implant sites[3]. A 2015 systematic review reported mean prevalence of peri-implant mucositis and peri-implantitis at 43% and 22% respectively[4]. An estimated 3 million people in the United States have at least one dental implant with the number growing by over 500,000 people annually[5]. Peri-implant disease presents a significant and increasing challenge to treat for both surgical and restorative clinicians[6,7].

Treatment options for peri-implant disease include a variety of non-surgical and surgical approaches to debride and decontaminate the infected pocket and implant surface. These approaches include but are not limited to the use of curettes, air-powder abrasion, titanium brushes, chemotherapeutics, regenerative therapies, and lasers[8,9].

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The use of lasers to treat peri-implant disease is an intriguing concept based upon the interaction of laser light with periodontal and peri-implant tissues, microorganisms and implant surfaces[12]. Laser-tissue interactions are physical processes used to create and control laser-induced tissue effects, which provide therapy for the patient. According to the latest scientific understanding, laser radiation, or light energy, must be converted into some other form of energy to produce therapeutic tissue effects. The atoms and molecules that comprise biological tissue ultimately absorb laser radiation and convert it into other energy forms. Laser-tissue interactions are often categorized according to whether laser energy, in the form of an electromagnetic wave, is converted into heat, chemical energy, or acoustic (mechanical) energy[12,13]. The emitted wavelength of any laser is highly focused and has the characteristic of being monochromatic, collimated and coherent[12]. Dental specific lasers for periodontal and peri-implant applications include diode lasers, gas lasers, and solid-state lasers, with emitted wavelengths that range from 600 nm to 10,600 nm[13]. The emitted wavelength from a laser, combined with the absorption characteristics of the wavelength into tissues and materials vary and guide their use in the periodontium[13]. The type of laser selected is based on the specific target such as tooth root, periodontal ligament, adjacent soft tissue (junctional epithelium and subepithelial connective tissue), alveolar bone, bacterial deposits (nonmineralized and mineralized plaque biofilms), and/or titanium implant surfaces[14]. The use of lasers to treat peri-implant disease is an emerging treatment option for implant clinicians. Several lasers have been utilized, including Neodymium-doped: yttrium, aluminum, and garnet (Nd:YAG), Erbium-doped: yttrium, aluminum, and garnet (Er:YAG), Carbon dioxide (CO_2), and diode lasers. Each laser manufacturer has different protocols, often proprietary, for addressing peri-implant disease. This has complicated reporting of results. According to the American Academy of Periodontology (AAP) Best Evidence Consensus on laser use to treat peri-implant diseases, evidence is equivocal with regard to achieving regeneration of supporting tissues around a diseased implant following laser use. The authors further concluded that current evidence is insufficient to determine what surface alterations may be occurring to dental implant fixtures and how this may ultimately affect treatment outcomes. Due to potential laser induced surface damages, a recommendation was made to determine the effect of laser energy on implant surfaces[10,11].

The Nd:YAG laser is designed to operate at the near-infrared wavelength of 1,064-nm and is delivered through the tip of a flexible fiber optic system of varying bundle diameters through free-running and pulsed waveforms[13]. The Nd:YAG laser energy is preferentially absorbed by pigmented tissues and poorly absorbed into water assisting in coagulation and tissue hemostasis[13]. The absorption characteristics of Nd:YAG laser make them ideal for oral applications. Periodontal uses include incision and excision of soft tissues, periodontal pocket curettage, removal of periodontal pocket lining epithelium, reduction of bacterial load in periodontal pockets, Laser-Assisted New Attachment Procedure (LANAP™) therapy, and implant surface decontamination in the peri-implant sulcus[14, 15, 16].

To understand clinically relevant surface changes and assess potential laser-induced damages, the main purpose of this *in vitro* study was to evaluate surface changes on titanium discs using the Nd:YAG laser at various clinically relevant angles in relation to the surface of the titanium discs to determine if a critical angle of the laser beam to the implant surface exists. This study will quantify surface damages to titanium discs following utilization of Nd:YAG laser at four angulations in relation the surface. In order to achieve the primary goal, a custom jig assembly was designed to standardize laser energy delivery to the titanium disc surfaces.

CHAPTER II: MATERIALS AND METHODS

This study was reviewed by WRNMMC IRB and found to be research not involving human subjects. The study was subsequently reviewed and approved by NPDS and NMPDC, Bethesda, Maryland. Ten titanium discs were used for each angulation group evaluated (parallel or 0, 10, 20, and 30 degrees), and a total of 40 discs were selected based on a sample size power analysis. A Zeiss LSM 980 confocal microscope was used to image ten discs that were randomly assigned to the control group, prior to laser treatment. The discs were imaged at five randomly selected points along the diameter. In order to appropriately analyze the images for surface topography, we “over scanned” the z dimension to capture “zero” intensity or sufficient blackness to pad the z stack on the top and bottom. This allowed for quadratic fit of the z position, centered on the highest intensity pixel within the z stack data. To simulate clinically relevant energy angles and remove the variability introduced by operator handling of the handpiece, 3D software/printing was utilized to build a custom jig assembly. A programmable linear actuator with the custom jig assembly (Figure 1) was used to expose the titanium disc surface to Nd:YAG laser across the diameter of the disc at a constant speed to allow 60-70 Joules of energy per disc. The test discs (aka post-laser) were imaged in the same manner as the controls (aka pre-laser). The test and control images were converted to topographical values utilizing FIJI software[21] to quantify titanium disc surfaces and surface changes following laser irradiation. 12 locations per image were randomly selected for surface topography measurements. These surface topography measurements were repeated for each image obtained. The FIJI imaging format stores metadata of the experiments and can be accessed openly for cross-platform data exchange. The confocal microscopic image metadata were compiled as a 3D image (CZI file format). Utilizing the “TopoJ” function, the surfaces of bright objects in the image stacks were analyzed (Figure 2).

Linear selections in the horizontal direction across the image enabled the “Plot Profile” which displays two-dimensional graphs of the intensities of pixels along a line within the image. The x and y data from each linear selection were saved and analyzed for variance.

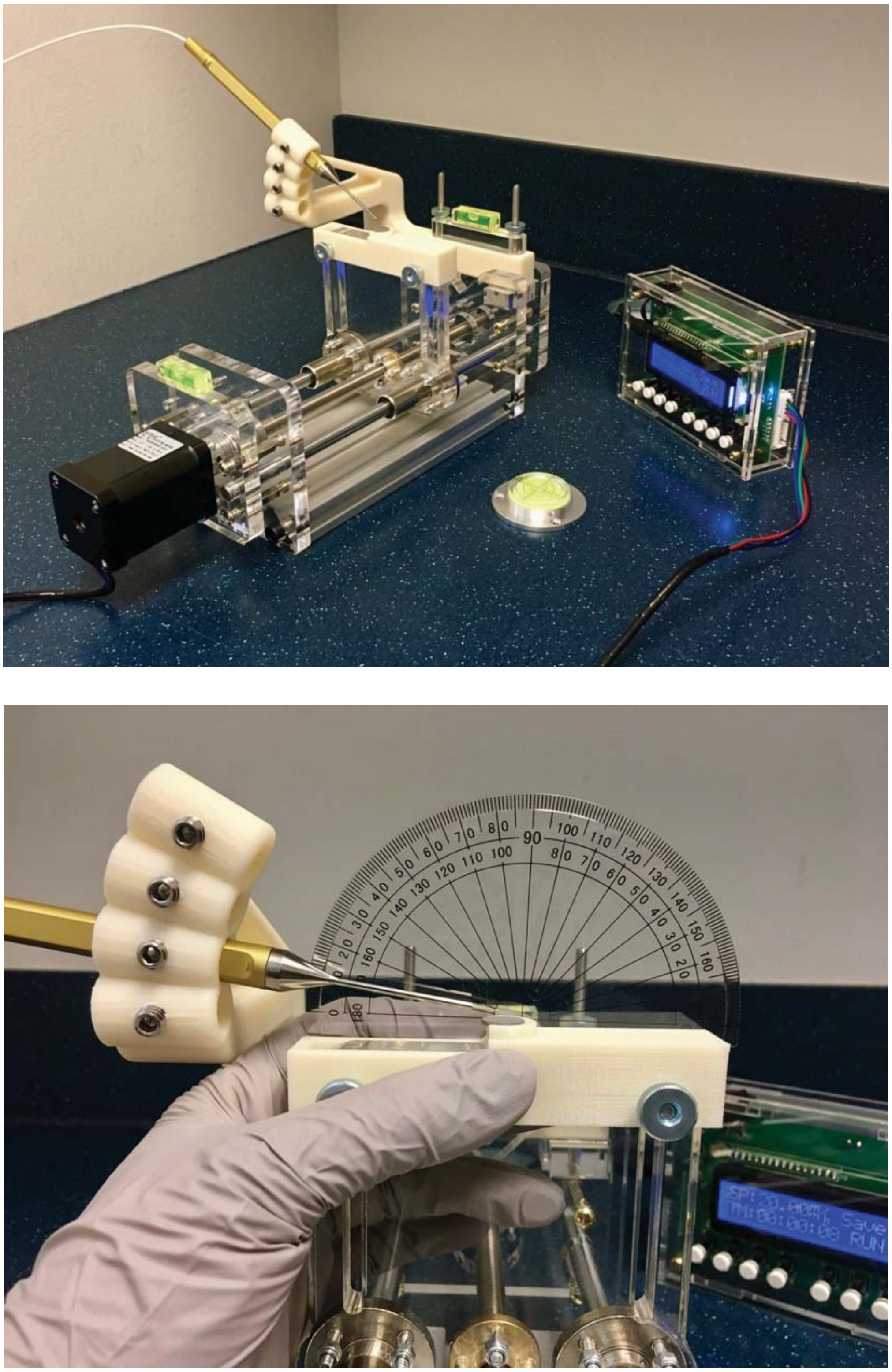


Figure 1 Programmable linear actuator with custom jig assembly. Note the angulations (0, 10, 20, and 30 degrees) of the laser handpiece fiberoptic in relation to the diameter of the titanium disc.

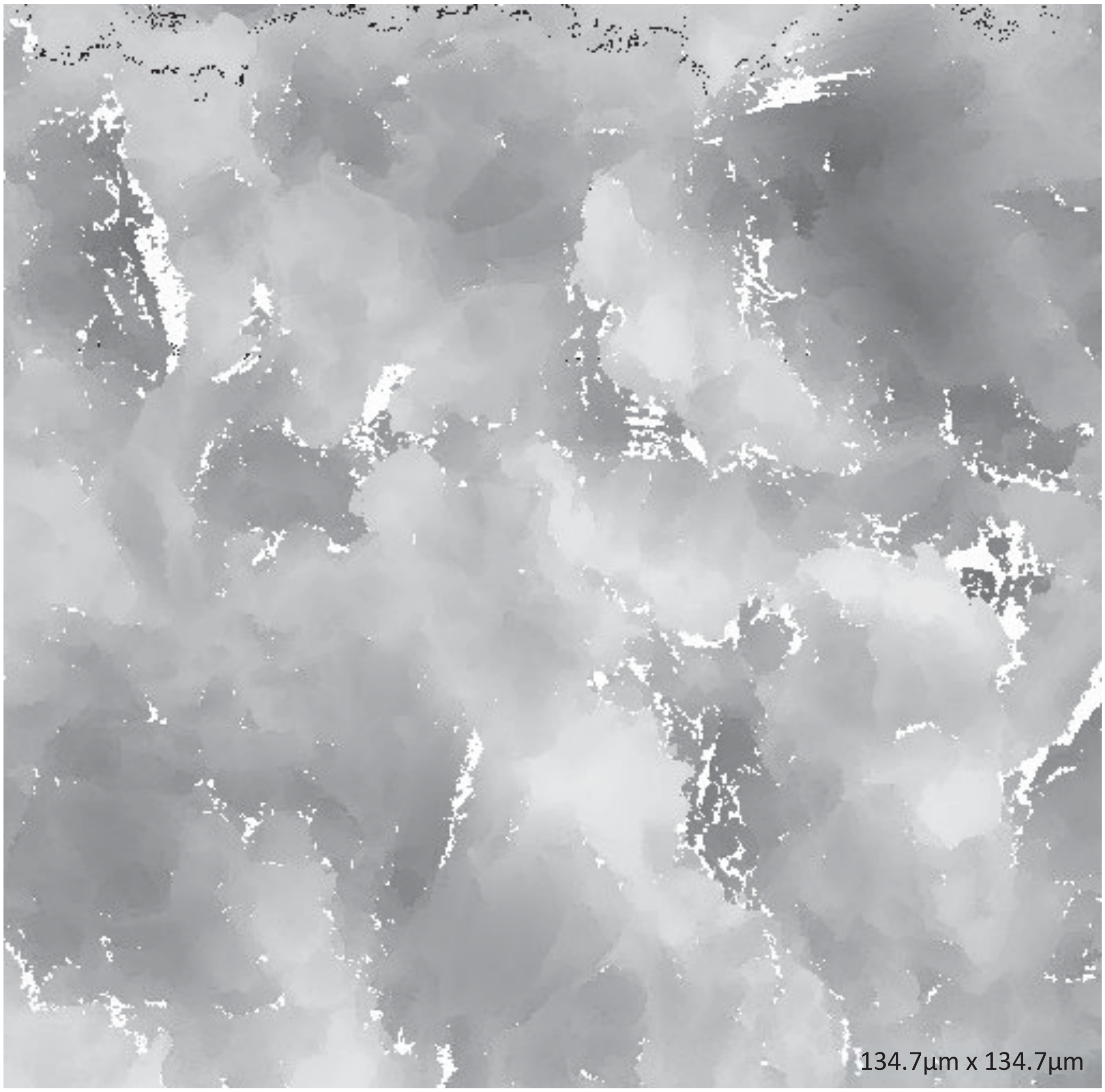


Figure 2 Surface topography analysis utilizing the TopoJ function of FIJI software

CHAPTER III: RESULTS

Confocal microscopy successfully provided ideal feature fidelity in small, lateral dimensions to quantify topographic values (Figure 3). The actuator assembly allowed a controlled and reproducible delivery of laser energy at the selected clinically relevant angulations. Control surfaces were generally uniform in topographic landscape. However, there were local areas where variations existed, averaging 16.6% variance. The variations were either higher peaks and valleys or topographically flat or smooth surfaces (Figure 4). Prior to the fabrication of the custom jig assembly for the standardization of angulation and laser energy exposure, trial laser irradiation was performed at 90 degrees to the titanium disc for interim image analysis (Figure 5). Images of the trial discs were taken from the center of a laser blast and a non-laser treated region on the perimeter of the lasered disc. Image analysis revealed that the individual laser "craters" or surface characteristics had almost immeasurably small depth. The image showed that the laser had ablated the fine surface features without changing the net shape of the titanium disc. This was evidenced by the consistent striations seen in the machined surface of the titanium macrostructure. The 50x image obtained with a Zeiss LSM 800 confocal microscope showed that the laser ablation had removed surface roughening produced by the manufacturer for enhanced osseointegration purposes.

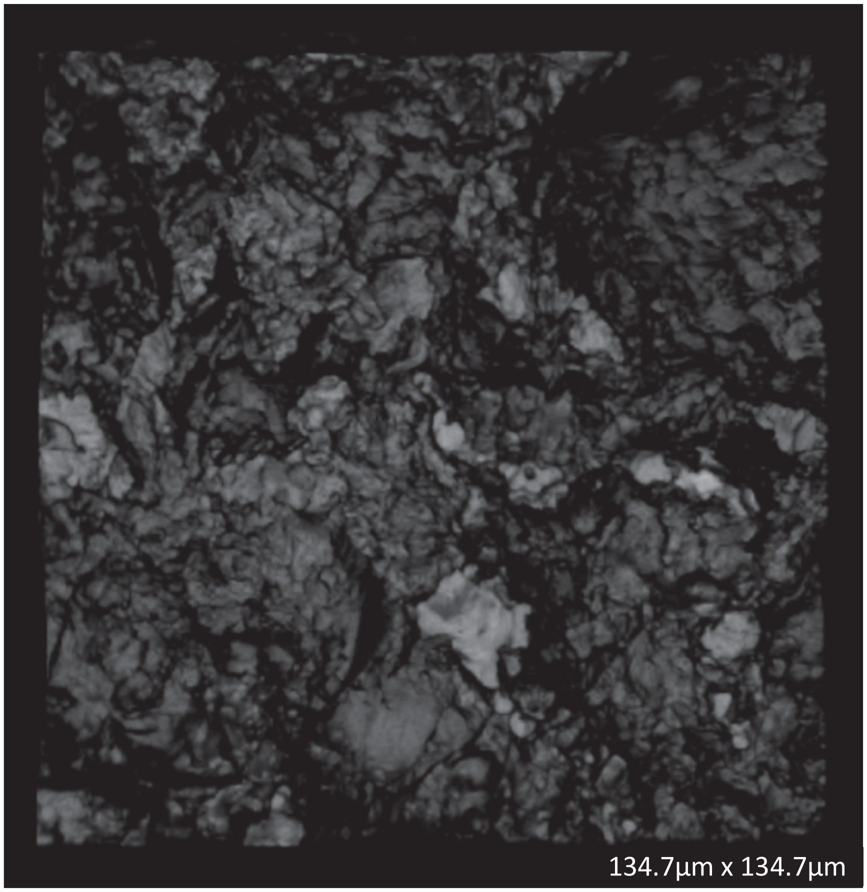


Figure 3 Confocal microscopic image of a control disc. Light shade represents peaks (high points) and dark shade represents valleys (low points).

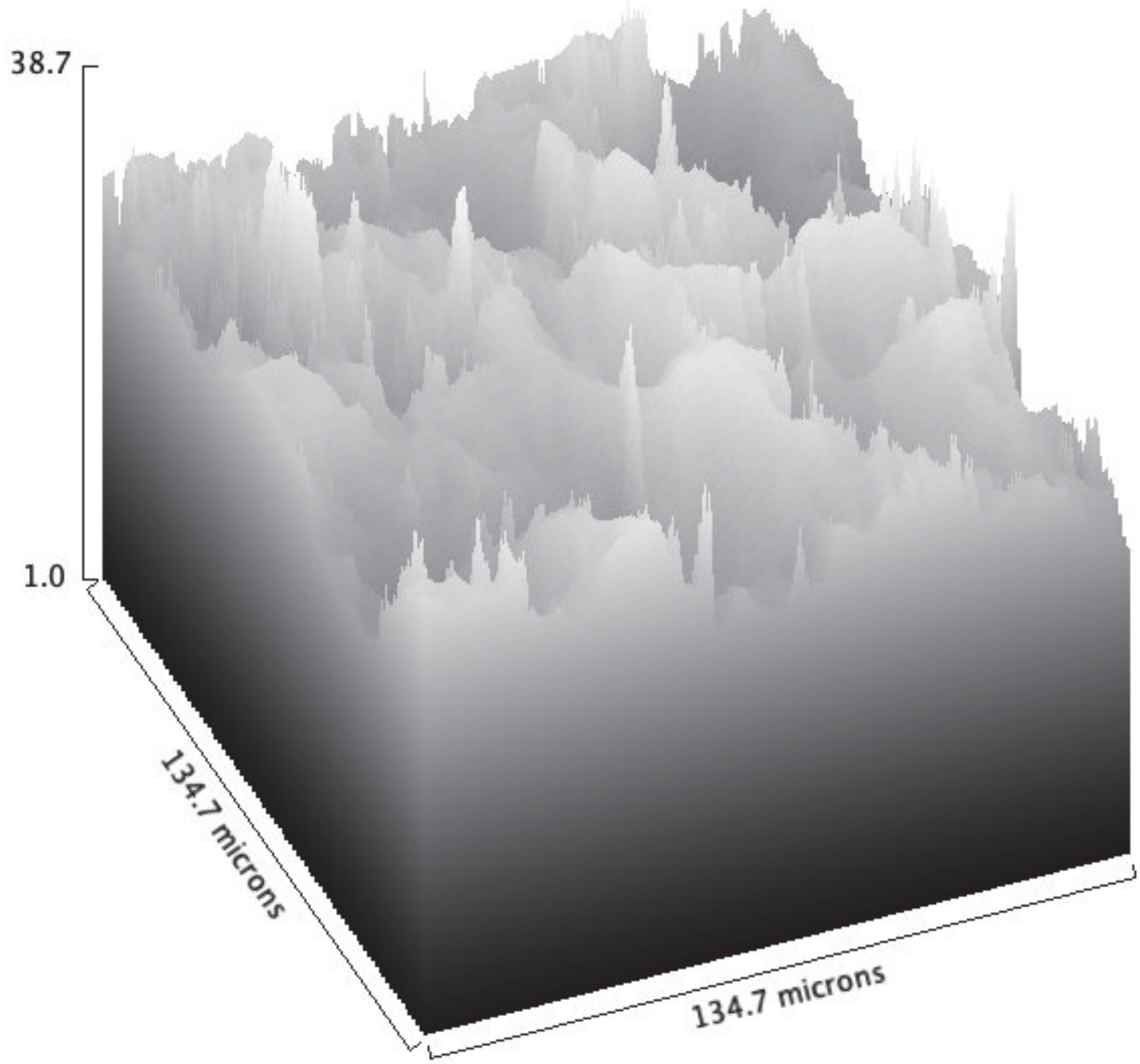
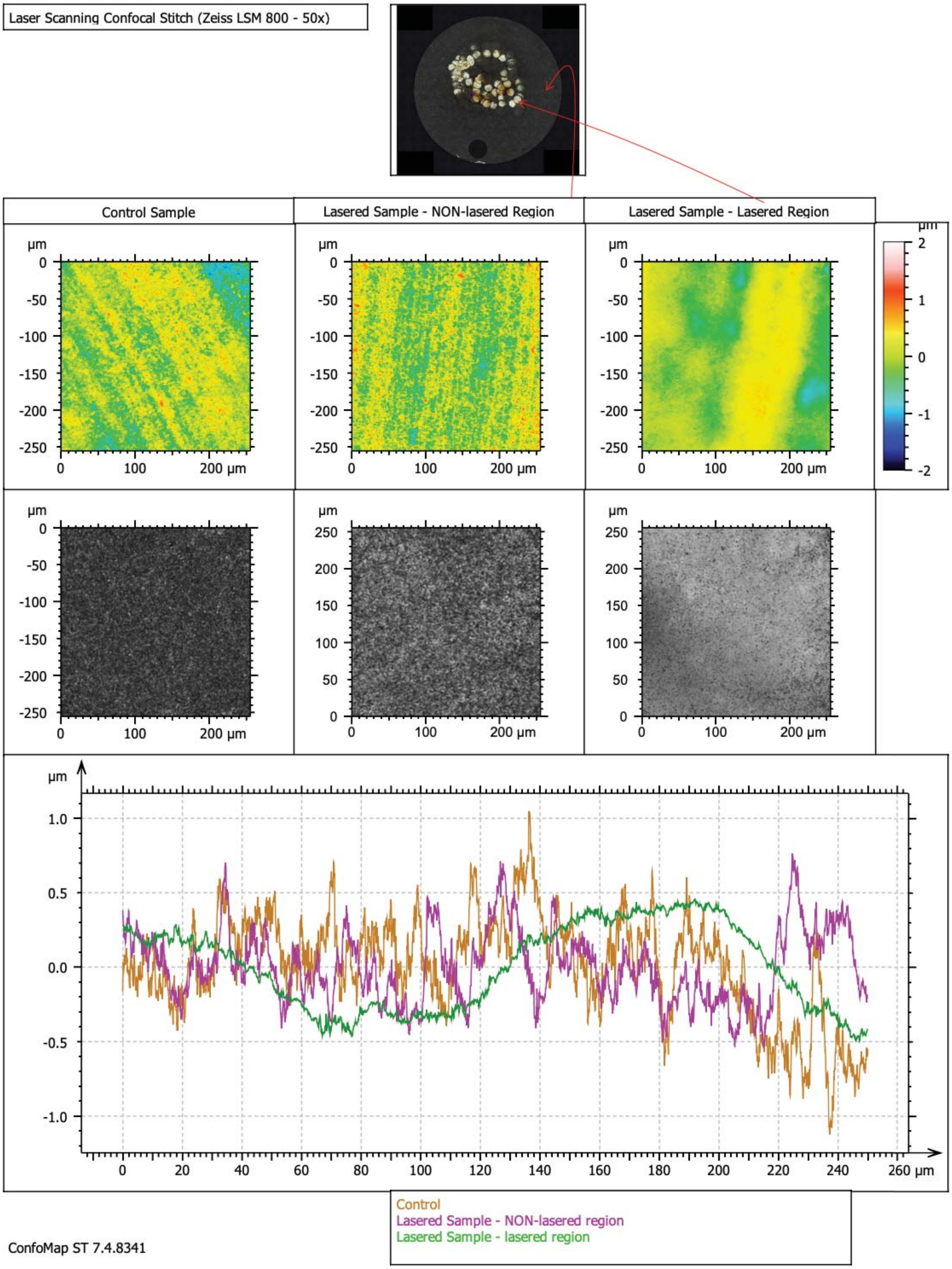


Figure 4 Three-dimensional surface plot of titanium control disc, note the surface variations of peaks and valleys.



ConfoMap ST 7.4.8341

Figure 5 50x confocal images were obtained from trial discs: One image from a non-lasered control and two images from a laser-irradiated disc, both at a lasered and non-lasered section for analysis. These images are shown both with and without colorization to illuminate the regular striations evident in the disc macrostructure. The striations are less evident in the non-colorized images and likely represent machining marks during disc creation from a turned rod of titanium. The rendering at the bottom of the figure shows the combination or overlay of the plot profiles from control, non-lasered, and laser-irradiated regions. The plot profile combination shows the changes of the surface characteristics in micrometers in the x and y directions. Note the loss of surface characteristics shown by the laser-irradiated (green) plot profile as compared to the control (gold) plot profile – the gold plot profile exhibits the local variance of the surface topography, whereas, the irradiated sample lacks the variance in microtopography.

CHAPTER IV: DISCUSSION

A major concern with the utilization of lasers in the peri-implant sulcus is the potential for surface alterations to the implant and damage to the implant-abutment interface. An *in vitro* scanning electron microscope (SEM) analysis by Romanos and colleagues evaluated sandblasted, plasma-sprayed, and hydroxyapatite-coated titanium discs (10mm diameter x 2.0mm thick), following exposure to an Nd:YAG laser.[17] The Nd:YAG laser was used in a pulsed mode at three power settings (2.0W, 4.0W, and 6.0W) and positioned 5.0 mm away from the disc surface. All implant analogs were irradiated for one minute. After the irradiation, the implants exhibited extensive surface damage that included melting, cracking, and dissolution, regardless of power setting. These findings of were in agreement with observations of Block and colleagues, who demonstrated that the Nd:YAG laser caused melting and alterations of plasma-sprayed titanium and hydroxyapatite-coated implant surfaces under 0.3W with 10 pulses per second (pps), 2.0W with 20pps, and 3.0W with 30pps power settings at a 5.0mm distance.[18] Kreisler and colleagues [19] concluded that the Nd:YAG and Ho:YAG lasers were not suitable for decontamination of dental implants due to the potential for surface damage. Their *in vitro* study utilized sandblasted and acid-etched, plasma-sprayed, hydroxyapatite-coated, and smooth titanium discs (10.0mm diameter x 1.5mm thick). The optic fiber of the laser was oriented at a 90-degree angle to the surface of the disc at a distance of 0.5mm, and discs were irradiated for 5.0 seconds without water cooling at various power settings. Under SEM imaging, the implant discs showed surface alterations including cracking, melting, and crater formation. It was noted that the damage observed was proportional to the power and was present at even the lowest power setting. One significant limitation of Kreisler's study is that the 90-degree angle at which the fiberoptic was positioned is not realistic and is contraindicated in most laser therapy protocols. For those reasons, the results may not be clinically relevant. Currently, there is considerable variation in methods and materials among experts who are researching laser-induced surface damages.

Over the past 50 years, dental implant surface technology has evolved in favor of a highly roughened nanotopography. The overwhelming consensus in the literature supports enhanced osseointegration and dental implant success with roughened versus smooth, machined surfaces[21]. While the successful treatment of peri-implant disease is predicated on high-quality surface decontamination, the impact of surface-altering decontamination methods on regenerative outcomes is unknown[8,9]. It is the author's opinion that the inappropriate application of laser energy to the implant surface could result in a significant decrease in surface roughness with a corresponding reduction in regenerative success.

In the clinical environment, maintaining ideal angulation of the laser energy relative to the diseased implant surface can be a difficult task. Common clinical challenges include patient cooperation and immobility, location of the implant in an anterior-posterior position for access, the contour of the dental implant crown (if present), and the maximum opening of patient at the implant location. Given the clinical reality of challenging access with all implant surface decontamination methods, it is the author's opinion that case selection plays a more critical role for the safety and success of laser implant decontamination. Severe damage to the titanium surface during misdirected laser or mechanical decontamination could generate metal debris in the treatment zone. While the biologic consequence of such debris is unknown, many factors can contribute to the presence of titanium in the sulcus, including methods described for implant surface decontamination associated with a diseased peri-implant sulcus[22, 23].

CHAPTER V: CONCLUSION

The orientation of the Nd:YAG fiber-optic in the peri-implant sulcus is critical. When the Nd:YAG laser interacts with titanium, inadvertent energy can negatively impact the manufactured surface characteristics. Our study indicates confocal microscopy successfully provided ideal feature fidelity in small, lateral dimensions for quantifiable topographic values and our custom actuator assembly allowed for a controlled and reproducible delivery of laser energy. Further experimentation and analysis are required to determine if a critical angle of the laser beam to the implant surface exists and if laser-induced alterations to the implant surface inadvertently disrupt osseointegration. The potential release of titanium particles and associated inflammation in the peri-implant sulcus are also of concern. The novel, custom jig assembly with downstream topographic analysis described here may prove to be an excellent means of standardization in future dental laser research.

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