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Assessing the Surface Modifications of Contaminated Sandblasted and Acid-Etched Implants Through Diode Lasers of Different Wavelengths: An In-Vitro Study

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Abstract

Objective: The present study was conducted to compare the effects of 810 nm, 980 nm, and dual (810: 50%—980: 50%) diode lasers on the surface modifications of implants contaminated by a standard strain of *Escherichia coli*.

Methods: Based on the operation on their surface, the implants were divided into six groups: “Group 1” was the positive control group undergoing no specific procedures. “Groups 2, 3, 4, 5, and 6” were contaminated by a standard strain of *E. coli*; “Group 2” was also set as the negative control group. “Groups 3, 4, and 5” were irradiated by 810 nm, 980 nm, and dual lasers (810: 50%—980: 50%; 1.5W, 320 μ m fiber) for 30 sec, respectively. “Group 6” was treated using standard titanium brushes. All groups were examined to evaluate the surface modifications by the X-ray diffraction analysis, scanning electron microscope, and atomic force microscopy.

Results: The values of carbon, oxygen, aluminum, titanium, and vanadium were significantly different in the surface composition of the contaminated implants from the control groups ($p=0.010, 0.033, 0.044, 0.016, \text{ and } 0.037$, respectively). In all target areas, there were significant differences in surface roughness ($p<0.0001$); the same was also true about the pairwise comparison of the study groups ($p<0.0001$). “Group 5” demonstrated lower morphological surface changes and roughness degrees.

Conclusions: Overall, laser irradiation could alter the surfaces of the contaminated implants. Titanium brushes and 810/980 nm lasers resulted in similar morphological alterations. Dual lasers enjoyed the least degree of morphological alterations and surface roughness.

Keywords: peri-implantitis, dental implants, X-ray diffraction, scanning electron microscopy, atomic force microscopy, diode laser, *Escherichia coli*

Introduction

DENTAL IMPLANTS ARE a practical treatment option to treat missing teeth¹ with successful and predictable long-term outcomes.² However, many patients have experienced implant failure and peri-implant diseases such as peri-implant mucositis and peri-implantitis. While the former

refers to a reversible plaque-induced inflammation of the soft tissues surrounding an osseointegrated dental implant,^{3,4} the latter is an inflammatory condition caused by the plaque that affects both the soft and hard tissues around a healthy dental implant with both clinical indications of inflammation and radiographic marginal bone loss.^{5,6} The success of any dental implant treatment depends on many factors, including the

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correct diagnosis and early treatment of inflammatory diseases around the implant.⁷ Meanwhile, proper geometry design and surface topography are prerequisites for implant treatment's short- and long-term success.⁸

Rougher implant surfaces promote the growth and persistence of more biofilms⁹ as significant contributors to the development of peri-implant diseases around the implants.^{10,11} During the progression of peri-implantitis, oral microorganisms and periodontal pathogens (primarily Gram-negative anaerobic bacteria) colonize the implant surface.^{6,12} Accordingly, patients with chronic periodontitis, poor plaque control, and no routine maintenance are more likely to develop peri-implantitis.¹³ Peri-implantitis can also have roots in systemic conditions such as uncontrolled diabetes, tobacco use, genetic predispositions, and excess cement following prosthetic procedures.¹⁴ To establish a healthy peri-implant tissue, the primary goal of treatment is to remove the biofilm surrounding the implant while the desired surface characteristics remain intact.¹⁵ Effective at-home oral care practices and nonsurgical treatments can facilitate the management of peri-implant diseases.¹⁶ Various treatment protocols are suggested to battle peri-implant inflammations: mechanical procedures (implantoplasty, curettes, sonic and ultrasonic scaling instruments, air abrasion, titanium brush),^{6,12} chemical treatment (topical chlorhexidine, citric acid, hydrogen peroxide),¹⁷ antibiotic therapy (tetracycline and minocycline),¹⁴ and more recently lasers (diode, CO₂, Er:YAG)¹⁶; nonetheless, there has been no consensus on a standard method.^{18,19} More conventional techniques are prone to bottlenecks: the mechanical methods damage the implant surface, resulting in a rough surface that harbors more bacteria and fails to maintain the treated implant fixture surface's biocompatibility for osteoblast and fibroblast adhesions.¹⁶ This prevents bone regeneration.^{12,20} Chemical surface treatment is not appropriate for all implant surfaces, and it has only a limited impact on plaque eradication.²⁰ Antibiotics give rise to resistant bacterial strains.¹⁴ Consequently, due to the difficulty accessing the implant surface and the surface's microscopic roughness, bacteria-colonized implants might be highly challenging to disinfect with conventional treatments,^{21,22} calling for more novel and practical approaches.

Light Amplification by Stimulated Emission of Radiation is what the term "laser" refers to. Medical lasers are based on the interaction of laser radiation with biological tissues, transferring focused and controlled energy to them.²³ The utilization of lasers as a minimally invasive method has continued to increase in treating many pathologic diseases in medicine. In addition to their effectiveness in surgery rooms, lasers have a variety of uses in ophthalmology, lithotripsy, cancer detection and treatment, dermatological and esthetic operations, wound healing, nerve stimulation, dentistry, etc.²⁴

The most commonly used lasers in dentistry are the Nd:YAG, Er:YAG, Er, Cr:YSGG, CO₂, and diode lasers at various wavelengths.^{16,25} Since lasers carry bactericidal effects and can remove toxins, they have been proposed as one of the newest treatment methods in managing peri-implant diseases.^{26,27} The energy fluence, amount of absorption, thermal conductivity, and surface structure of the material all affect how laser light interacts with metals.²⁸ Similar to the absorption coefficient, the spectral reflection capacity of each metal depends on the lasers' wavelengths.²⁹ Diode,

CO₂, and Er:YAG lasers are frequently used to treat conditions around implants thanks to their hemostatic properties, ability to selectively remove calculus, antibacterial properties by inactivating bacterial diffused toxins, and bactericidal effects.^{20,30–32} According to reports, one supplementary tool for treating peri-implant diseases with no implant surface abrasion^{33–35} is diode lasers.³⁶ The effectiveness of diode lasers on implant surface modification depends on their thermal effect, which leads to protein denaturation and cell lysis.¹⁷ Diode lasers have three wavelengths: 810, 940, and 980 nm. However, the 980 nm and the 810 nm lasers are the most frequently utilized to modify implant surfaces.³⁷ Diode lasers target melanin and hemoglobin, two pigments found in soft tissues.⁵ They can also inactivate pigmented Gram-negative anaerobic bacterial rods and disinfect rough and irregular implant surfaces that are challenging to reach through traditional mechanical debridement.³⁸

Nevertheless, the effects of the adjunctive use of diode lasers have not yet been extensively demonstrated in the management of peri-implant diseases. Although some findings have illustrated no additional clinical benefits in combining mechanical debridement with a diode laser,⁵ others found improved clinical and radiographic results.^{6,39–43} Most studies have focused on the decontamination efficacy of using lasers.^{38,39,44} At the same time, some should have also considered the surface changes (i.e., topographical changes and surface roughness) such techniques leave behind since high surface roughness helps bacteria escape the host defense mechanisms during the initial adhesion phase by reducing shearing forces and providing a vast surface area for bacterial attachment.⁴⁵

Therefore, this in-vitro study was conducted to assess the surface changes following the application of 810 nm, 980 nm, and dual (810: 50%—980: 50%) diode lasers on implant surfaces that were contaminated by a standard strain of *Escherichia coli*, compositionally by X-ray diffraction (XRD) analysis, morphologically by a scanning electron microscope (SEM) in a qualitative manner, and to determine the degree of surface roughness by an atomic force microscopy (AFM) test quantitatively.

Materials and Methods

This experimental-laboratory study was approved by the Institutional Research Ethics Committee of the Shahid Beheshti University of Medical Sciences, Tehran, Iran (IR.SBMU.RIDS.1395.274). The sample consisted of 24 implants randomly divided into six groups, each containing four implants; Group 1 (positive control group): healthy sandblasted and acid-etched (SLA) implants not infected with *E. coli* and not irradiated with the laser; Group 2 (negative control group): SLA implants infected with *E. coli* and not irradiated with the laser; Group 3: SLA implants infected with *E. coli* and irradiated by 810 nm diode laser; Group 4: SLA implants infected with *E. coli* and irradiated by 980 nm diode laser; Group 5: SLA implants infected with *E. coli* and irradiated by dual (810: 50%—980: 50%) diode laser; Group 6: SLA implants infected with *E. coli* and treated with the titanium brush. Given that the common periodontal pathogens are anaerobic organisms with a challenging laboratory culture medium, and their incubation

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on the surface of fixtures is probably associated with so much bias, it was decided to evaluate the effects of accumulation of a single bacterial strain on the surface of the fixture that grows in a short time and generates an acceptable amount of contamination on the surface of the fixture.

First, to create the least amount of chipping, turbine and carbide fissure burs were used to mark an area ($\sim 3 \times 5$ mm) on SLA implants (IDI Co., France, surface roughness: $1.7 \mu\text{m}$) in sterile conditions. The purpose was to expose a particular area of the implant surface to laser irradiation. The size of the target area was standardized by a World Health Organization periodontal probe. Then, 20 samples in sterile conditions were sent to a laboratory (Microbiology Laboratory of Shahid Beheshti University of Medical Sciences, Tehran, Iran) for microbial cultivation.

To ensure the samples were free of microorganisms and to avoid errors in the bacterial culture media, they were incubated for 15 min in an autoclave machine at 121°C and a pressure of 1.5 pounds. Then, the samples were cooled out of the device and placed in prepared microtubes. Next, BHI (brain heart infusion broth) medium was added to the implant containing microtubes (approximately twice the fixture height). Standard strains of *Escherichia coli* (ATCC25922) were passaged in a BHI culture medium (Merck, Germany). *E. coli* strains were incubated for 24 h and linearly cultured in MacConkey medium afterward. To prepare the bacterial suspension, two colonies of *E. coli* were removed from the MacConkey culture medium (by a sterilized swab) and poured into 2 cc physiological serum to reach 0.5 McFarland turbidity [1.5×10^8 colony-forming unit (CFU)]. The suspension was mixed on a shaker machine to obtain the appropriate concentration of bacteria. Next, the liquid mixture was measured in a spectrophotometer (Unico 2100, Spain) at a wavelength of 625 nm to measure suspension turbidity accurately. Based on Beer-Lambert law, the optical density (OD) rate was reported as 0.08 to 0.13. An OD between 0.08 and 0.13 was roughly equal to a concentration of 1.5×10^8 CFU/mL. A measure of 0.1 mL ($100 \mu\text{L}$) of the suspension prepared was added to each implant-containing microtube (Groups 2–5) by a sampler. The samples were also incubated for 24 h at 37°C . After this time, in the periodontal operating room, the specified (marked) areas in all samples (Groups 3–5) underwent laser treatment with a diode laser (QuickLase, Canterbury, United Kingdom; with a $320 \mu\text{m}$ tip size, power of 1.5W, application duration of 30 sec, and the same $796.17 \text{ W}/\text{cm}^2$ energy density for all groups). Irradiation was done for all laser groups in a continuous wave mode (using sweeping and rotating motions) and in a noncontact mode; a consistent distance of 1 mm was maintained between the delivery system's end and the surface of the specimen. Since the irradiation angle was 90° , the application of laser on the marked areas was standardized in a hand-guided manner. A power meter (FieldMaster GS, Coherent, Dieburg, Germany) was used to measure the average power output of the corresponding laser systems. The power meter was calibrated by the manufacturer before the experiment. Laser parameters are described in detail in Table 1.

Below is how the grouping was performed:

- Group 1 (positive control group): SLA implants ($n=4$) remained intact (not contaminated by *E. coli*, not subjected to the laser treatment).

TABLE 1. PARAMETERS OF THE LASER USED IN THE STUDY

Type of laser	Diode
Laser company	QuickLase, Canterbury, United Kingdom
Laser category	MD1104 GMDN 60340
Medium	GaAlAs Laser Diode Class IV
Emission mode	Continuous with a sweeping and rotating motion
Contact mode	Noncontact mode with a distance of 1 mm from all around the implants
Tip size	$320 \mu\text{m}$
Power density	$796.17 \text{ W}/\text{cm}^2$
Irradiation time	30 sec
Delivery system	Quartz Fiber
Energy distribution	Equally
Angle of radiation	90°
Peak output power	12W
Average output power	6W
Applied power	1.5W
Spot diameter at the focus	$320 \mu\text{m}$
Focal spot area	$320 \mu\text{m}$
Beam divergence	10
Water irrigation	NO
Air and aspirating airflow	NO

- Group 2 (negative control group): SLA implants ($n=4$) were contaminated by *E. coli* but did not undergo the laser treatment.
- Group 3: SLA implants ($n=4$) contaminated by *E. coli* and irradiated with an 810 nm diode laser for 30 sec.
- Group 4: SLA implants ($n=4$) contaminated by *E. coli* and irradiated with a 980 nm diode laser for 30 sec.
- Group 5: SLA implants ($n=4$) contaminated by *E. coli* were irradiated by a dual diode laser (810 nm:50%—980 nm:50%) for 30 sec.
- Group 6: SLA implants ($n=4$) contaminated by *E. coli* were treated by a titanium brush (PeriBrush™, Tigran™, Malmo, Sweden) for 30 sec with a torque of 10 N and speed of 40 rpm under irrigation of sterile serum to prevent temperature rise.

In the final step, all implants in the control and study groups were transferred to Razi Research Center, Tehran, Iran, for the XRD analysis to determine the weight percentages of carbon, oxygen, phosphorus, and titanium at their surface and to compare the changes in surface composition among different groups. X-ray diffractometer Seifert 3003 TT was used to examine the surface structures of the samples, and the General Structure Analysis System (GSAS) program was applied to produce Rietveld refinements for the quantitative phase analysis. The assessor who performed the test was completely blinded to the study groups. Statistical Package for Social Sciences (SPSS) 22.0 was used by a blinded statistician to analyze the data extracted from the XRD test. The statistical measures of mean and standard deviation (SD) were first calculated for each element to check whether there were any statistically significant differences in the values of carbon (C), oxygen (O),

TABLE 2. COMPARING THE MEAN AND STANDARD DEVIATION OF GROUPS WITH EACH OTHER

Groups	Carbon	Oxygen	Aluminum	Phosphorus	Calcium	Titanium	Vanadium
CONTROL + 810 nm	1.61±0.02	24.93±0.02	5.52±0.09	0.16±0.12	0	66.8±0.7	0.46±0.01
<i>p</i> Value	0.021*	0.021*	0.020*	0.014*	1.000	0.021*	0.021*
CONTROL – 810 nm	8.93±1.39	30.07±2.61	3.85±0.24	0.055	0	55.75±3.45	1.34±0.13
<i>p</i> Value	0.043*	0.564	1.000	0.131	1.000	0.248	0.248
CONTROL + 980 nm	1.61±0.02	24.93±0.02	5.52±0.09	0.16±0.12	0	66.8±0.7	0.46±0.01
<i>p</i> Value	0.021*	0.021*	0.020*	0.465	1.000	0.021*	0.021*
CONTROL – 980 nm	8.93±1.39	30.07±2.61	3.85±0.24	0.055	0	55.75±3.45	1.34±0.13
<i>p</i> Value	0.773	0.564	0.773	0.381	1.000	0.773	0.248
CONTROL + Dual	1.61±0.02	24.93±0.02	5.52±0.09	0.16±0.12	0	66.8±0.7	0.46±0.01
<i>p</i> Value	0.021*	0.248	0.020*	0.386	1.000	1.000	0.021*
CONTROL – Dual	8.93±1.39	30.07±2.61	3.85±0.24	0.055	0	55.75±3.45	1.34±0.13
<i>p</i> Value	0.248	0.043*	0.248	0.554	1.000	0.043*	0.309
CONTROL + Brush	1.61±0.02	24.93±0.02	5.52±0.09	0.16±0.12	0	66.8±0.7	0.46±0.01
<i>p</i> Value	0.021*	0.248	0.020*	0.885	0.317	0.021*	0.021*
CONTROL – Brush	8.93±1.39	30.07±2.61	3.85±0.24	0.055	0	55.75±3.45	1.34±0.13
<i>p</i> Value	0.149	0.773	0.773	0.375	0.317	0.773	0.248

*Indicates significant values.

aluminum (Al), phosphorus (P), calcium (Ca), and vanadium (V) among the six study groups. Afterward, rather than the analysis of variance (ANOVA) test, the Kruskal–Wallis *H* test was used as its nonparametric equivalent. The Mann–Whitney *U* test was also applied to perform a pairwise comparison between the groups.

The surface topography of all implants was evaluated using microphotographs at three different magnifications (500×, 1000× or 1K, and 2000s or 2K), obtained in a SEM vacuum chamber (Vega3, Tescan, Czech Republic). Two blindfolded assessors qualitatively assessed the SEM images for evidence of damage. Finally, relying on the AFM technique, a blinded assessor determined the surface roughness of the implants in three different areas on the implants; 10×10 μm, 5×5 μm, and 3×3 μm. The degree of surface roughness was quantitatively measured and reported using the Dualscope/Rasterscope SPM software (version 2.1.1.2, DME, Denmark). Data were analyzed by a blind statistician using SPSS software version 22.0. Central dispersion indices were calculated and reported for the degree of implant

surface roughness in study groups (mean±SD, 95% confidence interval). The one-way ANOVA was also used to compare the levels of surface roughness in each of the selected areas in different groups. As the results were significant, pairwise comparisons were made utilizing Tukey's test. In this study, type I error was set at 0.05.

Since the implants were randomly divided into groups, the laser operator in different wavelengths, the operators of each test (XRD, SEM, and AFM), the assessors of SEM images, and the statistician were blinded to prevent any bias.

Results

X-ray diffraction

A comparison between Groups 3 and 1 found significant changes ($p<0.05$) in carbon, oxygen, aluminum, phosphorus, titanium, and vanadium surface compositions. All elements in Group 3 (except calcium; $p=1.000$) were significantly different from their counterparts in Group 1. The surface composition of carbon in Group 3 also

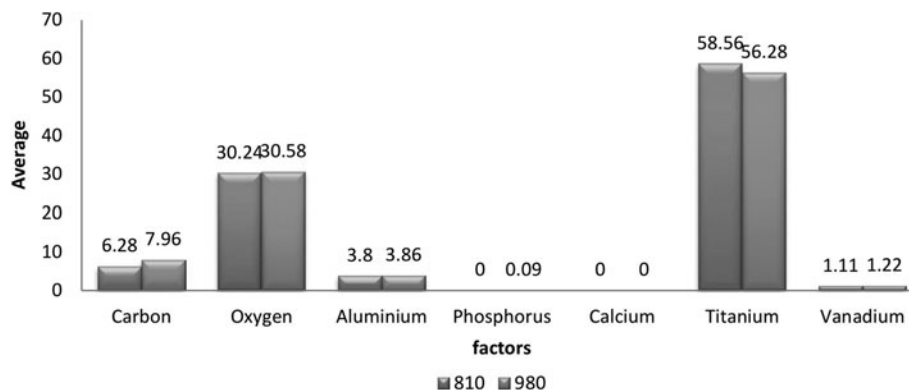
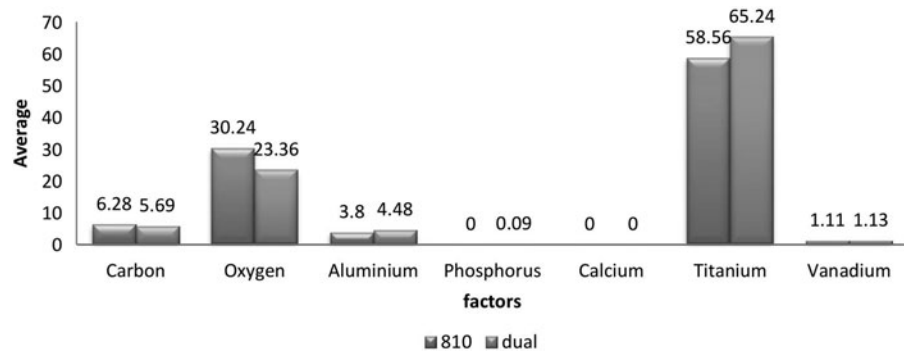


FIG. 1. Comparing the mean and standard deviation of Groups 3 and 4.

FIG. 2. Comparing the mean and standard deviation of Groups 3 and 5.



significantly differed from that of Group 2 ($p=0.043$; Table 2). Group 4 was also found to have a significantly different surface composition of carbon, oxygen, aluminum, titanium, and vanadium than Group 1 ($p<0.05$). All elements in Group 4 (except calcium; $p=1.000$ and phosphorus; $p=0.465$) had a significant difference compared to Group 1 (Table 2). Comparing Groups 4 to 2, none of the elements in Group 4 significantly differed from the negative control group ($p>0.05$). The comparisons made between Groups 5 and 1 showed that the changes in the surface composition of carbon, aluminum, and vanadium were significant ($p<0.05$); therefore, the elements in Group 5 (except calcium; $p=1.000$, titanium; $p=1.000$, oxygen; $p=0.248$, and phosphorus; $p=0.386$) were significantly different from what were measured in Group 1. The surface composition of titanium and oxygen in Group 5 significantly differed from that in Group 2 ($p=0.043$). Compared to Group 1, Group 6 experienced significant changes in the surface composition of carbon, aluminum, titanium, and vanadium ($p<0.05$). The elements in Group 6 (except calcium; $p=0.317$, oxygen; $p=0.248$, and phosphorus; $p=0.885$) were reported to be significantly different. However, none of the elements in Group 6 significantly differed from the negative control group (Group 2; $p>0.05$; Table 2).

Figure 1 shows the comparison between Groups 3 and 4. Only phosphorus experienced a significant change in the surface composition ($p=0.013$). As seen in Fig. 2, the surface compositions of Groups 3 and 5 were merely different in their levels of oxygen and phosphorus ($p=0.043$, 0.047). Figure 3 compares Groups 3 and 6 with significant changes in carbon and phosphorus ($p=0.043$, 0.047).

Where in Groups 4 and 5, the levels of oxygen and titanium were significantly different ($p=0.043$), no significant differences were observed between the elements in Groups 4 and 6. Figure 4 shows that carbon and titanium significantly differed in Groups 5 and 6 ($p=0.043$). Furthermore, Groups 1 and 2 had significantly different levels of carbon, oxygen, aluminum, titanium, and vanadium ($p<0.05$; Fig. 5).

The between-group comparisons were based on p value, mean, and SD. Accordingly, the surface composition of SLA implants contaminated by *E. coli* had significant degrees of changes in the levels of carbon, oxygen, aluminum, titanium, and vanadium ($p=0.010$, 0.033 , 0.044 , 0.016 , and 0.037 , respectively).

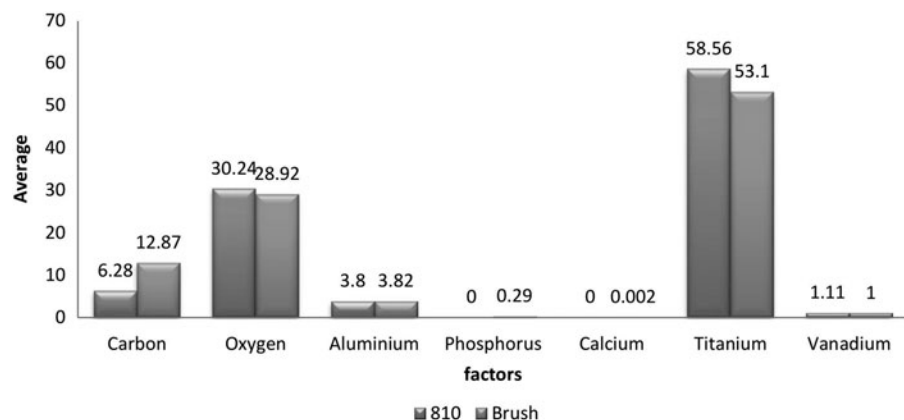
Atomic force microscopy

Within the $10 \times 10 \mu\text{m}$ selected area, the highest degree of surface roughness was found in the samples from Group 4 (mean $0.08 \mu\text{m}$). Other groups had mean roughness levels close to zero; it was $1.76 \mu\text{m}$ for the control groups.

Within the $5 \times 5 \mu\text{m}$ selected area, the highest levels of implant surface roughness were also observed in Group 4 (mean $0.084 \mu\text{m}$), followed by the samples in Group 3 ($0.029 \mu\text{m}$). Other groups had mean roughness levels close to zero; it was $1.76 \mu\text{m}$ for the control groups.

Within the $3 \times 3 \mu\text{m}$ selected area, the highest levels of surface roughness were measured and reported in Group 6 (mean $0.027 \mu\text{m}$); the samples in Group 3 had lower levels of surface roughness (mean $0.013 \mu\text{m}$) compared to the brush intervention group. Other groups had roughness levels close to zero; it was $1.76 \mu\text{m}$ for the control groups.

FIG. 3. Comparing the mean and standard deviation of Groups 3 and 6.



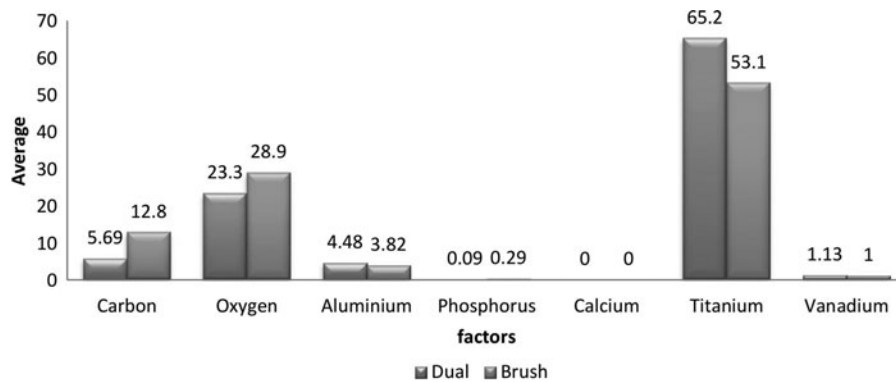


FIG. 4. Comparing the mean and standard deviation, Groups 5 and 6.

Table 3 illustrates the central dispersion indices of the implants contaminated by the standard *E. coli* strain once the implants were exposed to diode laser irradiation with different wavelengths or received brush treatment. Significant differences in the surface roughness of implants were measured and recorded in different groups and the selected areas (all $p < 0.0001$). Significant pairwise differences were analyzed and documented using a Tukey's test (all $p < 0.0001$).

Scanning electron microscope

Figures 6–8 demonstrate SEM images of the surface of the studied implants after different treatment interventions. According to the current study, surface irregularities and roughness were more prominent in the dual laser-treated samples. The irregularities and numerous ups and downs were abundant on the implant surfaces. The surfaces of noncontaminated implants (Group 1) also were unsmooth with irregular lines, as did the samples in Groups 3, 4, and 6. Moreover, the minor surface morphological changes (detectable in the laser-treated groups) were in agreement with the results of the AFM test. The surface changes and roughness degrees appeared to be lower in the dual laser group.

Discussion

Although recognized as reliable replacements for tooth loss, dental implants can offer surfaces for bacterial colonization in the mouth.^{46–48} Peri-implant inflammation may be brought on by bacterial adhesion on implant surfaces and other elements, including the host immune system.^{47,48} In

addition, unmanaged inflammation continuously erodes the alveolar bone surrounding the dental implants, probably resulting in implant failure.⁴⁹ According to a report, surface characteristics like material composition, roughness, and wettability may impact how well bacteria adhere to surfaces.^{50,51} For implants to properly osseointegrate, the surface roughness causes a mechanical interlock between the implant and bone. However, increased peri-implantitis and ionic leakage may be a significant risk with higher surface roughness. These two consequences can be limited by 1–2 μm of average roughness.^{8,52} According to clinical studies, the rough titanium implant surface exposed in the oral cavity may be the best surface for bacterial colonization. In addition, metal maintenance tools (like ultrasonic debridement) with metal tips can increase surface roughness and may impact bacterial adhesion and proliferation on the implant surface.^{46,53}

Therefore, the current study aimed to evaluate the surface modifications of implants contaminated by standard strains of *E. coli* using minimally invasive diode lasers of wavelengths of 810 and 980 nm and a dual-wavelength diode laser. The study took advantage of the qualitative morphological evaluations by SEM and quantitative measures (i.e., XRD for determining surface compositional changes and AFM to measure the surface roughness generated following each technique) to assess how the surface structure of implants might be modified using laser settings vis-à-vis the titanium brush (as a standard mechanical debridement technique) compared to control groups.

The present study found that all methods applied resulted in significant compositional changes following the surface treatment. The results of SEM demonstrated that a 980 nm

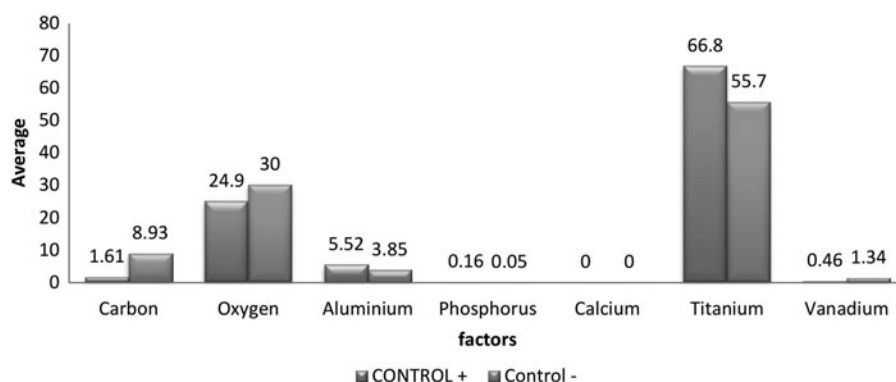


FIG. 5. Comparing the mean and standard deviation, the positive and negative groups.

IMPLANTS' SURFACE MODIFICATION BY DIODE LASERS

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TABLE 3. DISPERSION INDEX OF THE SURFACE ROUGHNESS VALUES FOR TREATED IMPLANTS IN DIFFERENT GROUPS ACCORDING TO THE TARGET AREAS

Area	Group	Mean	Standard deviation	95% confidence interval	
				Lower range	Higher range
10×10	810 nm laser	0	0	0.078	0
	980 nm laser	0.08	0	-0.022	0
	Dual laser	0	1.0	0	2.0
	Brush	0	0	0.019	0
5×5	No laser	0	0	0	1.0
	810 nm laser	0.029	0.031	0.004	0.055
	980 nm laser	0.084	0	-0.029	0
	Dual laser	0	0	0	0
3×3	Brush	0	0	0.009	0
	No laser	0	0	-0.006	0
	810 nm laser	0.013	0.011	0.004	0.022
	980 nm laser	0	0	-0.039	0
	Dual laser	0	0	0	0
	Brush	0.027	0.032	0.0002	0.054
	No laser	0	0	-0.002	0

diode laser (5, 10, and 15W, continuous wave, contact mode) applied on titanium disks neither caused any damage nor modified the disk surface; there was no discernible difference between lasered and nonlasered surfaces regardless of the power setting.⁵⁴ Similar results were obtained

from the study by Castro et al³³ on TiOblast ST implants, where titanium surfaces were found undamaged and unaltered by the SEM analysis. After being exposed to the 980-nm diode laser, there was no discernible difference between lasered and unlasered titanium surfaces regardless of the power setting.³³ Gonçalves et al³⁴ focused on applying 2.5 and 3W diode lasers with 980 nm wavelength on machined surfaces, revealing that SLA implants demonstrated no surface damage.

Similarly, Faramarzi et al.²⁰ applied an 810 nm diode laser of different settings (1.5, 2.5, 3.5, 4.5, 5.5 W for 5 and 10 sec) to non-SLA implants and found that there were no noticeable morphologic changes or melting on implants at 1.5, 2.5, and 3.5 W of laser irradiation and that the surfaces in SEM studies resembled the surfaces of the nonirradiated group. However, there were surface alterations after exposure to 4.5 and 5.5 W for 5 and 10 sec. Mainly, substantial melting was evident following a 10-sec exposure to 5.5-W diode laser beams. As a result, the diode laser beams up to 3.5 W were beneficial in treating peri-implantitis since they did not harm implant surfaces. It was also revealed that an 810 nm diode laser at 2, 4, and 6 W power settings did not create any apparent surface changes on polished and SLA surfaces independent of the power density.⁵⁵ Kreisler et al²⁸ showed that the irradiation of an 810-nm-diode laser did not damage surfaces, including SLA, plasma sprayed, hydroxyapatite-coated, and smooth titanium disks. Moeintaghavi et al⁵⁶ also found that the least number of surface modifications was seen after diode laser irradiation (2W, 810 nm, 10 s) on titanium implants with Laser-Lok microchannels and

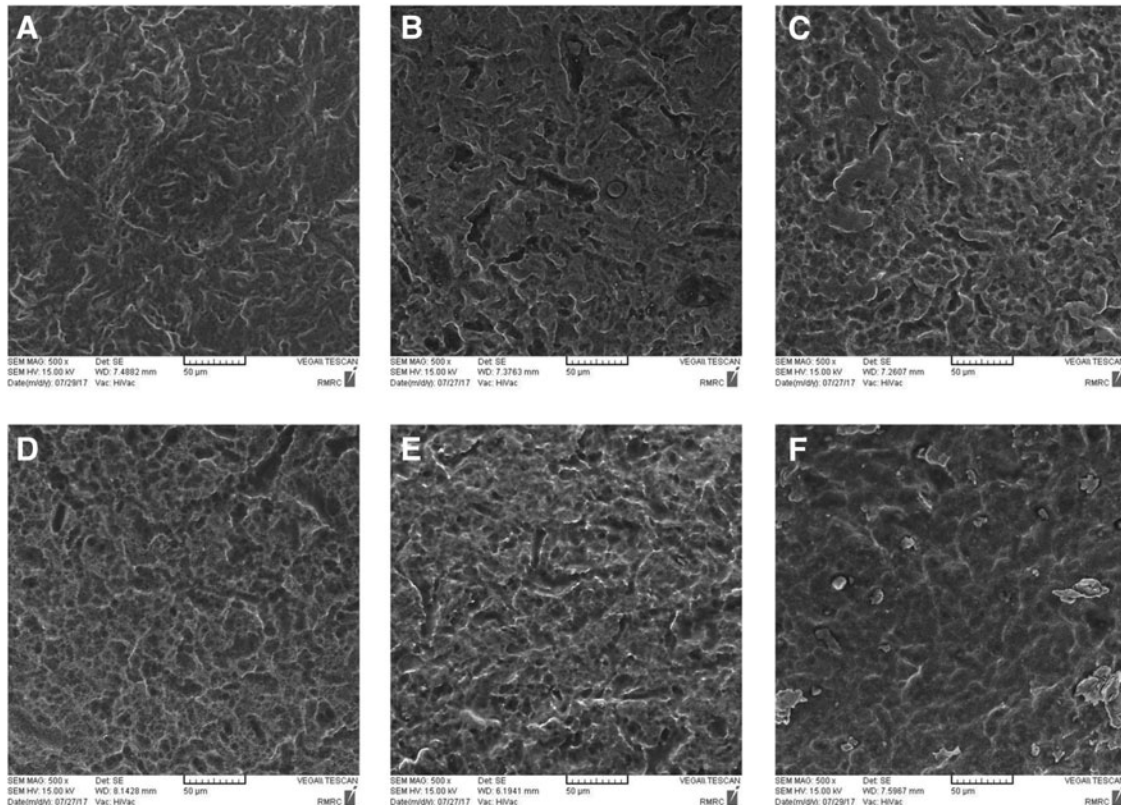


FIG. 6. SEM with 500×magnification; (A) Positive control group; (B) Negative control group; (C) 810 nm laser; (D) 980 nm laser; (E) Dual laser; (F) Titanium brush. SEM, scanning electron microscope.

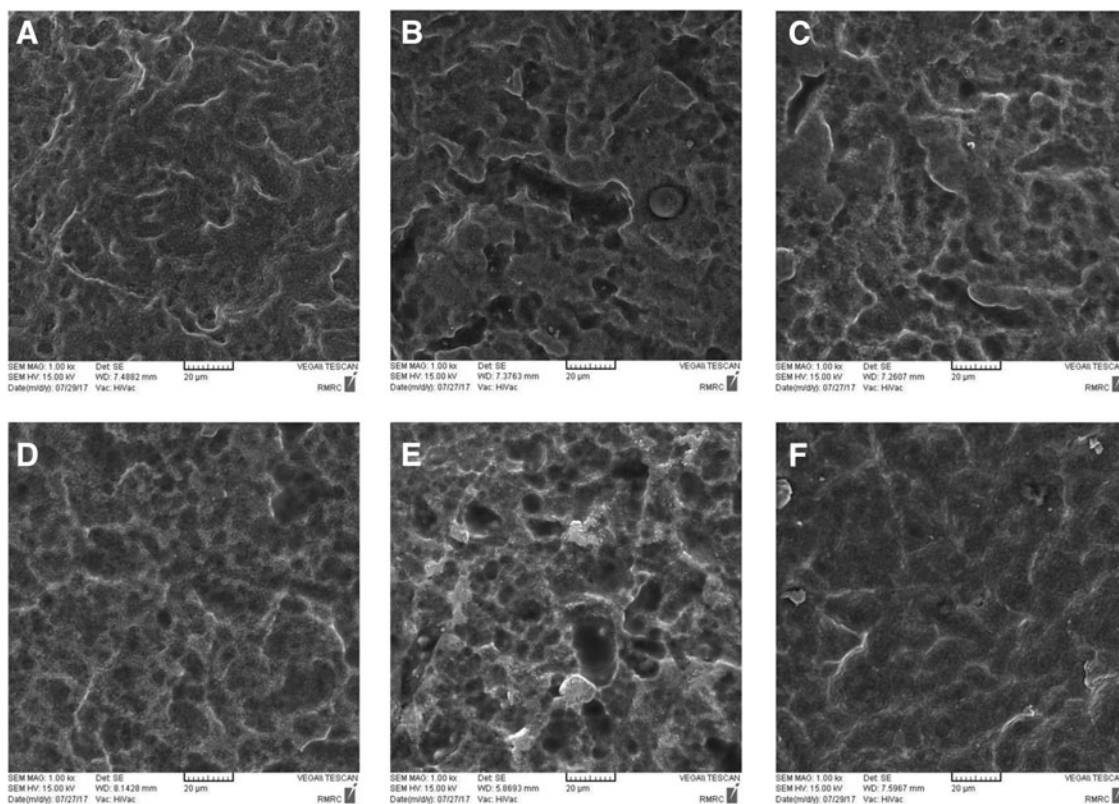


FIG. 7. SEM with 1000×magnification; (A) Positive control group; (B) Negative control group; (C) 810nm laser; (D) 980 nm laser; (E) Dual laser; (F) Titanium brush.

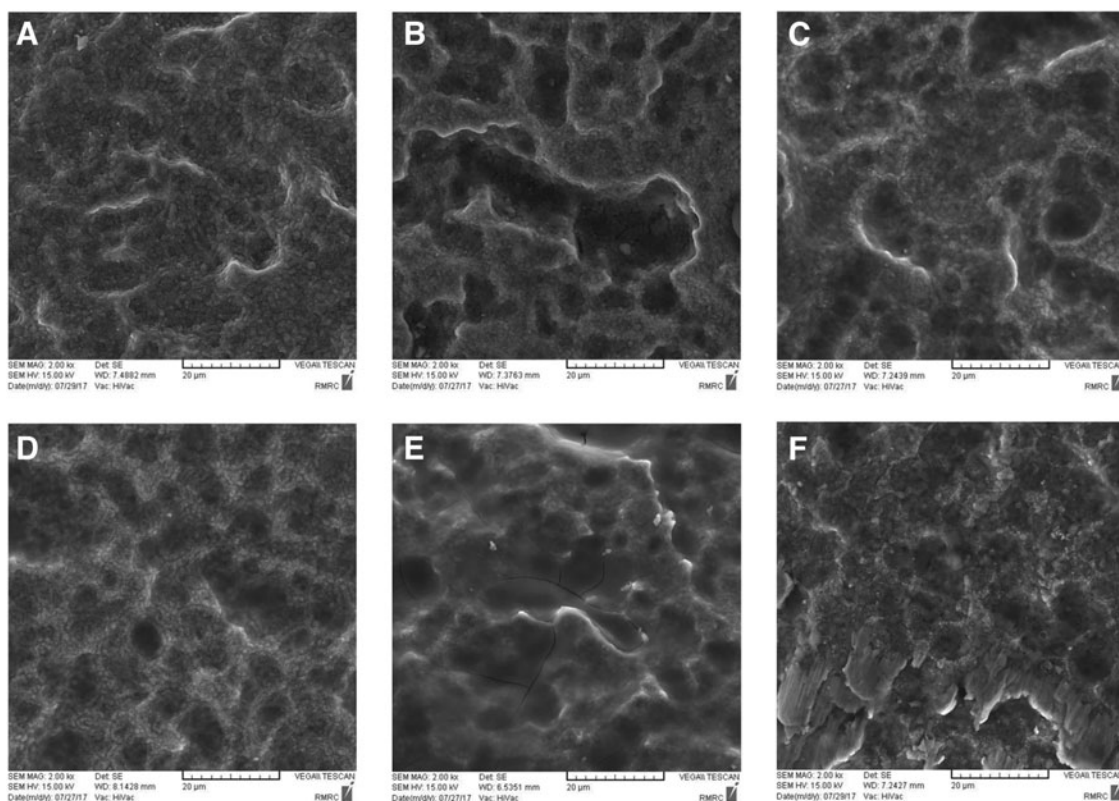


FIG. 8. SEM with 2000×magnification; (A) Positive control group; (B) Negative control group; (C) 810nm laser; (D) 980 nm laser; (E) Dual laser; (F) Titanium brush.

surfaces prepped with resorbable blasting media and that (consistent to our results) it had no effects on the features of the implant's surface.

Although in most of the studies mentioned above, no surface alterations were found following both 810 and 980 nm diode laser irradiations, we found minimal changes that were discernible in small areas of surface evaluations both in AFM and SEM; however, the dual laser setting resulted in lower surface roughness.

There are some possible reasons for inconsistencies between our results and other studies. First, these studies did not compare the effect of diode laser wavelengths on the surface modifications to see any possible differences; other laser parameters were also quite heterogeneous between our research and others. Second, the variation in results might have been because the mentioned studies used titanium materials with different surface characteristics. Next, in contrast to our research, some others used a treatment regimen with high energies clinically not practicable as they dramatically increased the temperature on the implant surface.⁵⁵ Further, all other studies applied SEM tests to evaluate the surface changes of irradiated implants; thus, the reported results were likely subjective.

On the contrary, our study coupled SEM with the AFM technique to quantitatively measure the surface roughness among study groups, eliminating the subjective role of researchers in interpreting the results. Finally, these differences are shown in an in-vitro setting, and they might not be of any importance in a clinical setting: the present study relied on micron-sized areas to measure and record the differences in surface roughness among different laser groups; this was a substantially small region allowing the authors to obtain conclusive clinical results. Therefore, the diode laser irradiation with clinically appropriate parameters could be considered to have minimal harmful effects on the surface of the SLA implants.

The limitations of this study were the inability to include more implant specimens due to the high costs, not using the actual peri-implants-causing microorganisms in the oral cavity for contaminating implant surfaces, and the in-vitro nature of the research. Given that the oral cavity is impacted by saliva, gingival crevicular fluid, and blood and that access to the implant surfaces would be more challenging in the oral environment than in an experimental setting, it would be reasonable to assume that the results would have changed to some extent if the study had been conducted in a clinical trial. These limitations are worth to be considered in future studies.

Conclusions

Laser irradiation can modify the surface compositions of the treated implants. Dual lasers could induce the least amount of morphological changes, while 810 and 980 nm lasers and titanium brushes may bring about comparable outcomes. Diode lasers with single wavelengths could create higher roughness on the implant surfaces, as quantified in the study; however, the surface roughness could reach its lowest degree following dual-laser irradiation.

Authors' Contributions

M.N.D.: Conceptualization, methodology, formal analysis, investigation, resources, data curation, writing—original

draft, writing—review and editing, visualization. B.H.: Conceptualization, methodology, validation, project administration. S.A.M.: Software, formal analysis, investigation, resources, data curation, writing—original draft, writing—review and editing, visualization. M.T.: Conceptualization, methodology, validation, supervision.

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