

Study of the Structure of the Implant Surface and the Effectiveness of Various Methods of Implant Treatment with Peri-Implantitis

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Abstract

The aim of the study was to compare the effectiveness of decontamination of various types of implant surfaces removed due to the diagnosis of peri-implantitis using implantoplasty, titanium brush and Er;Cr;YSGG 2780nm laser.

We studied 30 dental implants, including 3 control implants, one from each manufacturer, and 27 experimental implants obtained from patients diagnosed with peri-implantitis. We used the implantoplasty method, titanium brush, and Er; Cr;YSGG 2780nm laser for cleaning the surface. For studying the cleaning efficiency and evaluating the elemental composition of the surface we used scanning electron microscopy. It was found that the most effective method is decontamination of the surface with a laser, which allows to preserve the microabrasion as much as possible and effectively remove bacteria and other substances adhered to the implant.

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Introduction

Nowadays, dental rehabilitation of patients with dental implants is a predictive treatment method. The popularity of this method is growing, and with it the number of complications increases¹⁻³. It is not easy to make a decision what method of treatment to choose when a patient is diagnosed with "peri-implantitis". Moreover, to date, there are no clear protocols and clinical recommendations in the treatment of peri-implantitis. Doctors face this complication both at the early and long-term treatment periods.¹⁻⁷ Due to these facts the relevance of the chosen topic is beyond doubt. According to a number of researchers, microbial decontamination of the implant surface is a key factor in the success of the treatment of peri-

implantitis. There are two main methods of treating the infected surface of the implant: chemical – using various antiseptics, and physical, which includes a mechanical method and a laser treatment method⁸⁻¹³. It is crucial to realize which method, depending on the type of implant surface, will be the most optimal in every clinical situation¹⁴. In the treatment of peri-implantitis, it is important to understand how well and effectively the granulation tissue will be removed, the conditions for the regeneration of the defect and the integration of the newly formed bone tissue with the implant surface will be provided.

One of the most interesting and promising methods of cleaning the implant surface is treatment using laser technologies. Currently, a large number of studies have been devoted to the effect of various types of lasers on the inflammatory focus around the implant and the implant itself. The main objective of such treatment is to achieve microbial decontamination of the implant surface¹³⁻¹⁵. It is known that the surfaces of implants, depending on the manufacturer, differ in surface cleanliness¹⁶. Moreover, chemical elements from the implant surface may accumulate in the

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surrounding tissues: bone and mucosa, and this may affect the immune system^{17,18}. This fact, as a consequence, will affect the quality and dates of osseointegration and the immune response of the body, respectively, the success of the treatment. For now, clinicians are in a difficult position regarding the choice of treatment method for peri-implantitis. There is no consensus in the literature about the effectiveness of one method. Due to the above, the treatment approaches of peri-implantitis are still relevant. The aim of this study is to evaluate the effectiveness of surface treatment of implants removed with a diagnosis of peri-implantitis and treated with a titanium brush, implantoplasty, and Er;Cr;YSGG 2780nm laser.

Materials and methods

The objects of the study were 27 removed implants with a diagnosis of "peri-implantitis", which functioned from 3 to 10 years, and three new ones-one from the manufacturer of each type of surface, taken as control group (in the manufacturer's package). We examined 9 implants from three manufacturers with different surfaces: 1-NobelBiocare (Sweden), TiU-nite surface (anodized titanium dioxide); 2-XIVEDentsplay (Germany), SLA surface (sandblasting with aluminum oxide, acid etching); 3-BioHorizons (USA), RBM surface (tricalcium phosphate treatment/ acid etching). After removal the implants were subjected to the following types of treatment to clean the surface: 1-a diamond bur (grain size-red marking); 2-a special brush for cleaning the surfaces of implants made of Ti-Ni alloy (Neobiotec); 3 – Er; Cr; YSGG laser with a wavelength of 2780 nm with the following characteristics: power 1.5 W, frequency 20 Hz, water/air 20/20. We studied two surfaces of each implant: 1-an infected surface that was in direct contact with the granulation tissue; 2 – treated (with bur, brush, or laser). All the data obtained were compared with the control implant of each type.

Electron microscopy methods were used for performing the study of the morphology and elemental composition of the implant surfaces, depending on the type of treatment and in comparison with the control implant. Electron microscopy studies were carried out in the laboratory of electron microscopy of the Center for Collective Use of the Siberian Federal

University on a scanning electron microscope (SEM) JEOLJSM 7001-F (Japan), equipped with an energy-dispersive spectrometer IN-CAPentaFETx3. We studied the surface morphology in secondary electrons at magnifications of x1500 and x5000. The elemental analysis of the implant surface was carried out by energy-dispersive X-ray spectroscopy (EDX).

Results and Discussion

Electron microscopy methods were used to study the surfaces of control and removed implants (diagnosed with peri-implantitis). Energy-dispersive microanalysis was used for analyzing the elemental composition of the surface and the impurities found on it.

SEM images of the surface of NobelBiocare control implants (based on commercially pure class 4 titanium (G4Ti), TiU-nite surface (anodized surface-titanium dioxide) are shown in Fig. 1a, 1b.

The surface of the control implant is microporous (Fig. 1a), at the nanolevel - smooth with extended microcracks (Fig. 1b). The method of energy-dispersive X-ray spectroscopy revealed the impregnation with phosphorus (P), which is the standard in the manufacture of this surface (Fig.1c, Table 1). The type and composition of typical spectra reflecting the chemical elements present in these regions are shown in Fig. 1c, and Table 1.

Analysis of the surface of the TiU-nite implant (with peri-implantitis) showed the presence of microporosity (Fig. 2a, 2b) and phosphorus (P) (Fig.2f), carbon contamination (C) – in the obtained spectra, its amount ranges from 12.34 to 14.46 at.% (Table 1, spectrum 1,2). Also, aluminum contamination (Al) from 0.29 to 0.39 at.% was detected in the studied areas and silicon contamination (Si) - from 0.46 to 0.51 at.%. In addition to this, potassium (K) from 0.4 to 0.55 at.% and calcium (Ca) from 21.37 to 25.22 at.% were found on the surface (Table 2). The contamination, found on the TiU-nite surface (Fig. 2b), contains carbon (C), aluminum (Al), silicon (Si), phosphorus (P), and calcium (Ca), which, apparently, is associated with their diffusion from the bone tissue, and the proportion of phosphorus and carbon is significant.

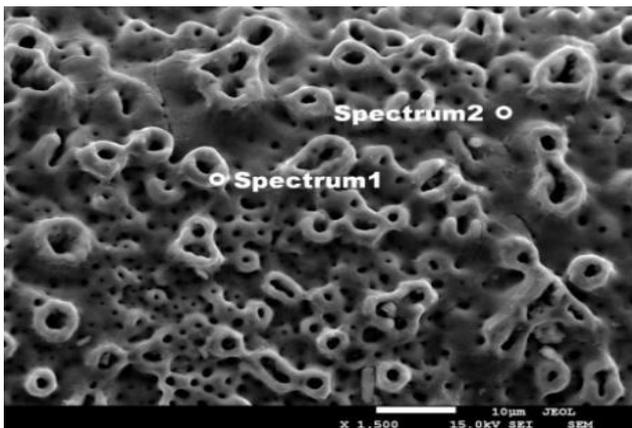


Figure 1.a

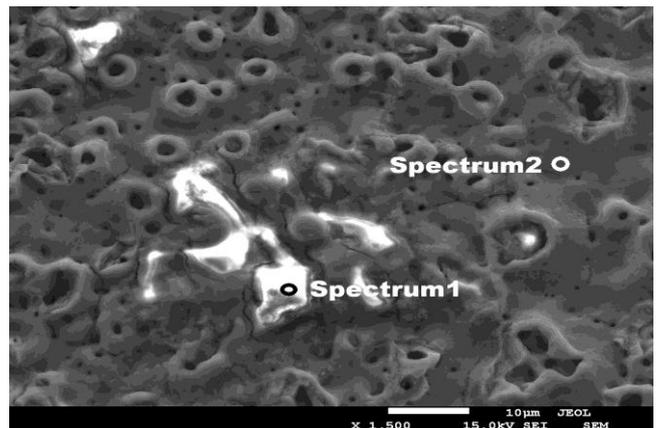


Figure 2.a

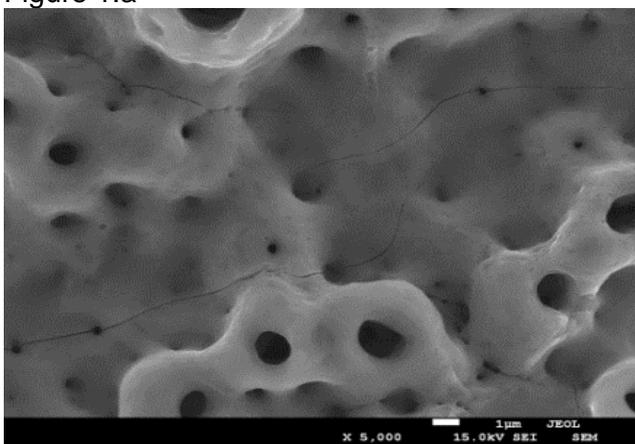


Figure 1.b

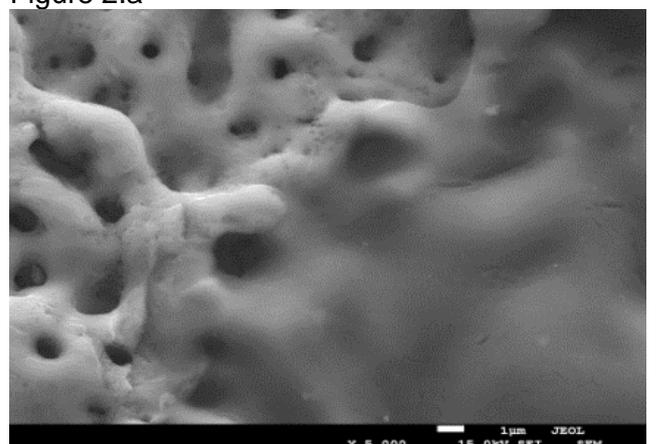


Figure 2.b

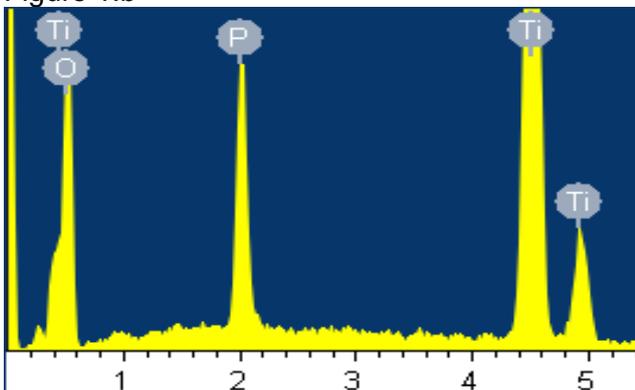


Figure 1.c

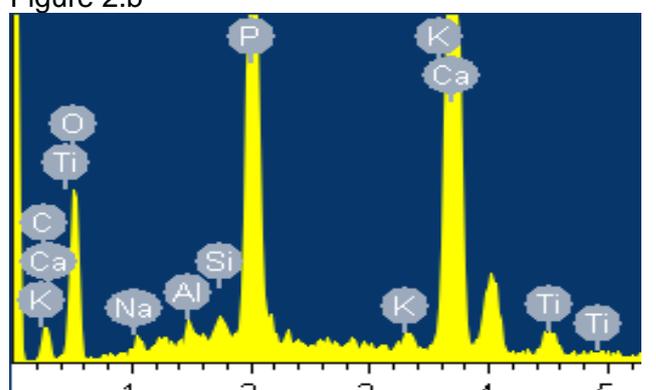


Figure 2.c

Figure 1. SEM image of the TiU-nite surface of the control implant surface: a – with point spectrum markers, x1500, b – x5000, c – elemental spectrum.

| Spectrum | Number of chemical elements, at. % | | |
|------------|------------------------------------|------|-------|
| | O | P | Ti |
| Spectrum 1 | 68.54 | 4.92 | 26.53 |
| Spectrum 2 | 57.49 | 6.76 | 35.75 |

Table 1. Elemental composition of the spectra obtained on the surface of the NobelBiocare control implant, TiU-nite surface (Fig.1a).

Figure 2. SEM image of a typical TiU-nite surface and the elemental spectrum of an implant with a diagnosis of peri-implantitis: a – with markers of point spectra, x1500, b – x5000, c – general view of the spectrum.

| Spectrum | Number of chemical elements, at. % | | | | | | | |
|------------|------------------------------------|-------|------|------|------|-------|------|-------|
| | C | O | Na | Al | Si | P | K | Ca |
| Spectrum 1 | 14.46 | 39.16 | 0.71 | 0.39 | 0.51 | 17.58 | 0.55 | 25.22 |
| Spectrum 2 | 12.34 | 37.97 | | 0.29 | 0.46 | 10.46 | 0.46 | 21.37 |

Table 2. Elemental composition of the spectra

3f). Significant contamination with carbon (C) and nickel (Ni) was also detected (Table 3), these elements are part of the alloy from which the brush is made. Thus, the amount of carbon in the studied spectra is determined from 12.72 to 66.67 at.%, the amount of nickel (Ni) from 6.52 to 15.11 at.%.

A study of the SLA surface of XIVE Dentsplay implants (Germany) showed that the control implant has a micro-rough surface, heterogeneous due to significant contamination (Fig.4a, 4b).

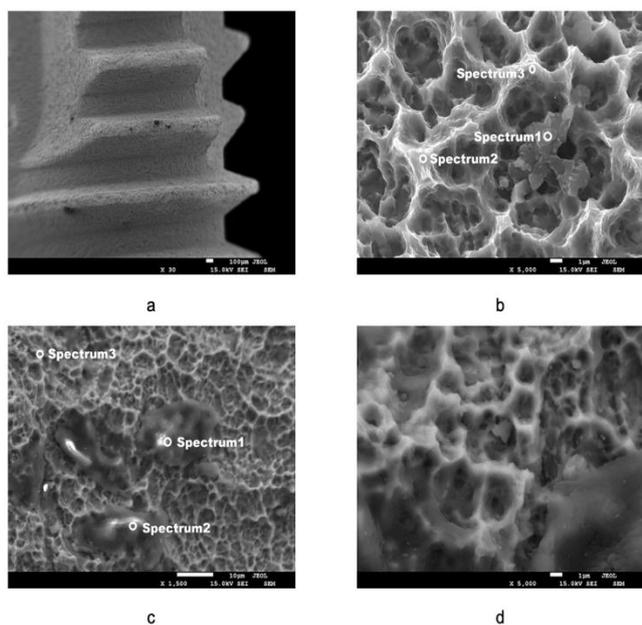


Figure 4. SEM image of a typical SLA surface of implants XIVEDentsplay: a – general view; b – control implant; c, d – the implant with peri-implantitis. Note: magnification x30(a), x1500 (c), x5000 (b,d).

On the SLA surface of the implants, a high content of carbon (C) was detected. The amount in the studied areas ranges from 23.21 to 75.91 at.% , aluminum (Al) from 0.11 to 0.15 atomic % , silicon (Si) from 0.14 to 0.19 atomic % , sulfur (S) from 0.26 to 0.62 at.%, chlorine (Cl) from 0.72 to 1.43 at.%, zinc (Zn) from 1.35 to 1.97 at.%, calcium (Ca). On the surface of the implants without contamination, the spectra showed 100% of titanium (Ti), which, apparently, is the norm (Table 4).

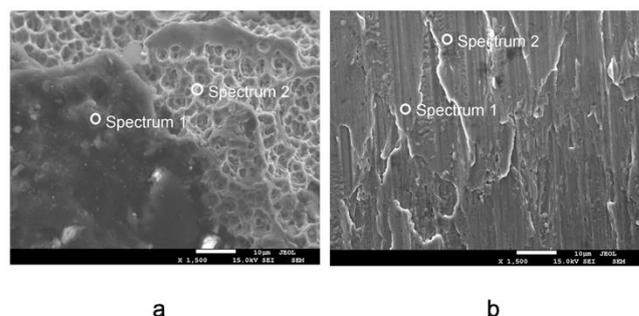
The surface of SLA implants with a diagnosis of peri-implantitis is micro-rough, heterogeneous due to heavy contamination (Fig. 4c, 4d), the structure is almost identical to the control implant.

A large number of chemical elements were found in the contamination's composition, especially the high content of carbon (C) from 35.55 to 76.77 at.% , there are aluminum (Al), silicon (Si), sulfur (S), calcium (Ca). The number of elements in the studied spectra does not significantly differ from the control implant, we did not detect chlorine (Cl) and zinc (Zn), which are determined in the control group (Table 4).

| Spectrum | Number of chemical elements, at. % | | | | | | | | | |
|--|------------------------------------|-------|------|------|------|------|------|------|-------|------|
| | C | O | Al | Si | S | Cl | K | Ca | Ti | Zn |
| Control implant (Fig. 4a, 4b) | | | | | | | | | | |
| Sp 1 | 75.91 | 15.46 | 0.13 | 0.14 | 0.26 | 0.72 | – | 0.22 | 6.30 | 1.97 |
| Sp 2 | 48.39 | 19.01 | 0.11 | 0.25 | 0.62 | 1.43 | 0.17 | 0.90 | 27.89 | 1.35 |
| Sp 3 | 23.12 | – | 0.15 | 0.19 | 0.41 | – | – | – | 75.56 | 0.91 |
| Implant with a diagnosis of peri-implantitis (Fig. 4c, 4d) | | | | | | | | | | |
| Sp 1 | 70.54 | 7.44 | 1.67 | 1.72 | 0.65 | – | 0.66 | – | 17.32 | – |
| Sp 2 | 76.77 | 20.52 | 0.32 | 0.10 | 0.46 | – | – | 0.18 | 1.65 | – |
| Sp 3 | 35.55 | – | – | 1.98 | 0.31 | – | – | – | 62.16 | – |

Table 4. Elemental composition of the spectra obtained on the SLA surfaces of the XIVE Dentsplay control implant and diagnosed with peri-implantitis.

The SLA surface, treated with laser, looks significantly cleaner, even compared to the control implant. This is evidenced by a decrease in the amount of carbon (C), which ranges from 3.15 to 4.14 at.% , no aluminum (Al), sulfur (S) (Table 5). There are traces of melting with microcracks on the surface (Fig 5a, 5d). Presumably, there is no harmful effect from the melting of the surface, since the spectra obtained on it are pure, the amount of titanium (Ti) is 66.58 at.%, carbon (C) is 4.14 at.% and oxygen (O) is 29.28 at.%.



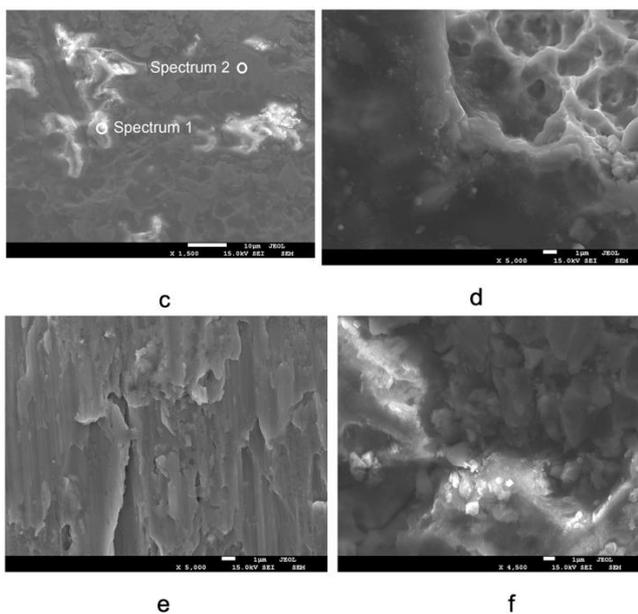


Figure 5. SEM image of a typical SLA implant surface XIVEDentsplay with peri-implantitis after treatment with: a, d – laser; b, e – diamond bur; c, f – special brush.

Note: magnification x1500 (a,d,c), x5000 (d,e,f).

The surface of SLA (with peri-implantitis) after treatment with diamond bur has a completely disturbed macro-and microstructure. Traces of diamond bur are the notches and furrows (Fig. 5b, 5e). The elemental composition of the surface is quite clean in comparison even with the control implant. The amount of carbon is very high in all the spectra, ranging from 46.76 at.% to 58.51 at.% (Table 5) - this indicates contamination of the implant surface with small diamond particles that broke off from a bur during treatment (Table 9, Fig. 8a).

The SLA surface with peri-implantitis, treated with a brush made of an alloy containing Ni and Ti, looks like it has preserved the macrostructure, but has completely lost the microstructure (roughness). Furrows and notches left by the brush are found on the surface (Fig. 5b, 5f). The elemental composition of the implant surface after treatment is significantly cleaner than the composition of both the control surface and with the peri-implantitis. However, a large amount of carbon (C) on the SLA surface (from 11.00 to 27.73 at.%), (Table 5) is explained by its presence on the brush, which is confirmed by energy-dispersion microanalysis (Table 8, Fig. 7b).

| Spectrum | Number of chemical elements, at% | | | | | | | | | | |
|----------|----------------------------------|-------|------|-------|-------------|-------|---------------------------|-------|------|-------|-------|
| | C | O | Al | Ti | C | Ti | C | O | Na | P | Ca |
| | Laser | | | | Diamond bur | | Brush made of Ni-Ti alloy | | | | |
| Sp 1 | 32.76 | 32.89 | | 34.36 | 5.93 | 94.07 | 27.73 | 37.73 | 0.66 | 11.73 | 20.80 |
| Sp 2 | 13.69 | 13.47 | 0.29 | 72.56 | 7.47 | 92.53 | 11.00 | | | | 89.00 |

Table 5. Elemental composition of the spectra obtained on the SLA surface of the XIVE Dentsplay implant with a diagnosis of peri-implantitis after treatment.

The results of the study of the surface of BioHorizons implants (USA) (the main material is Ti-6Al-4V class 5 titanium alloy (G5Ti), the RBM surface was subjected to tricalcium phosphate treatment and acid etching) are shown in Fig. 6, 7. The RBM surface of the BioHorizons control implant is micro-rough, relatively clean (Fig. 6a, 6c), a slight impregnation with phosphorus (P) and calcium (Ca), presumably remaining after the treatment is found (Table 6).

On the surface of the RBM implant with a diagnosis of peri-implantitis, micro-roughness was also detected (Fig. 6b, 6d), inclusions, the elemental composition of which includes a large amount of elements such as carbon (C), (from 53.34 to 59.26 at.%) and nitrogen (N), the amount of which is from 22.09 to 24.62 at.% , oxygen (O) in the amount of 17.50 to 20.98 at.%, phosphorus (P) in the amount of 0.22 to 0.31 at.% , sulfur (S) in the amount of 0.50 to 0.68 at.% , not a significant amount of calcium (Ca) and titanium (Ti) (Table 6).

The RBM surface of the implant with a diagnosis of peri-implantitis after laser treatment retains the microstructure, but has traces of melting (Fig. 7a, 7d). It looks much cleaner and the elemental composition almost corresponds to the composition of the control implant, only the presence of oxygen (O) in the amount of 41.81 to 49.06 at.%, it indicates the formation of oxides on the surface as a result of laser melting (Table 7).

Besides, no elements such as calcium (Ca) and phosphorus (P) were found, but the high amount of oxygen (O) was found, which indicates the formation of oxides on the surface of the implants during the crystallization of micro-volumes of molten metal under the laser treatment.

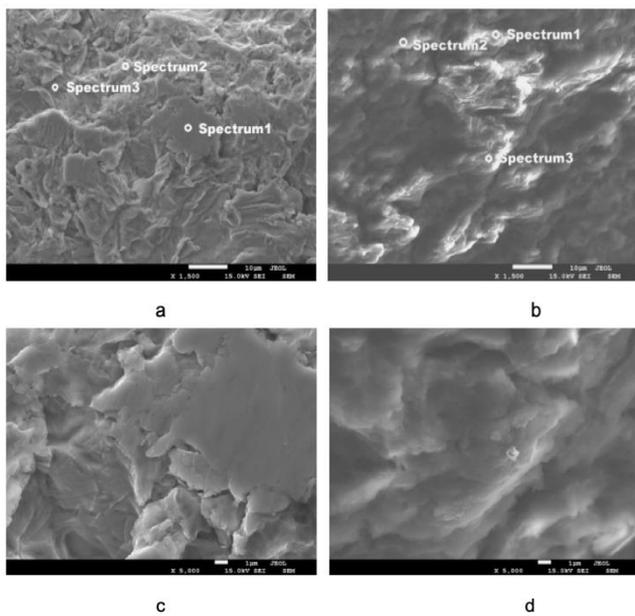


Figure 6. SEM image of a typical RBM surface of BioHorizons implants: a, c – a control implant; b, d – an implant with a diagnosis of peri-implantitis. Note: magnification x1500 (a,b), x5000 (c,d).

| Spectrum | Chemical elements, at. % | | | | | | | | | | | |
|----------|---------------------------|------|------|-------|------|--|-------|-------|------|------|------|------|
| | Al | P | Ca | Ti | V | C | N | O | P | S | Ca | Ti |
| | Control implant (Fig. 5a) | | | | | Implant with a diagnosis of peri-implantitis (Fig. 5b) | | | | | | |
| Sp1 | 8.35 | | 0.76 | 87.05 | 3.84 | 53.34 | 24.62 | 20.98 | 0.23 | 0.50 | 0.05 | 0.29 |
| Sp 2 | 8.31 | 1.15 | | 87.61 | 2.94 | 57.12 | 24.78 | 17.09 | 0.22 | 0.69 | | 0.11 |
| Sp 3 | 10.00 | | 0.46 | 86.25 | 3.29 | 59.26 | 22.09 | 17.50 | 0.31 | 0.68 | 0.06 | 0.11 |

Table 6. Elemental composition of the spectra obtained on the RBM surface of BioHorizons implants, Fig. 5.

The RBM surface with a diagnosis of peri-implantitis treated with diamond bur completely lost its surface morphology (Fig. 7b). Traces of bur in the form of furrows and notches are observed on the surface, and bur's cutting fragment embedded in the implant's surface is clearly visible (Fig. 6e). The elemental composition of the surface is quite clean (Table 7) and practically corresponds to the composition of the control implant (Table 7). However, there is a significant presence of carbon (C) in the amount from 5.18 to 93.76 at.%, which is especially negative, since it is present in inclusions in the form of micro-fragments from diamond bur formed during treatment.

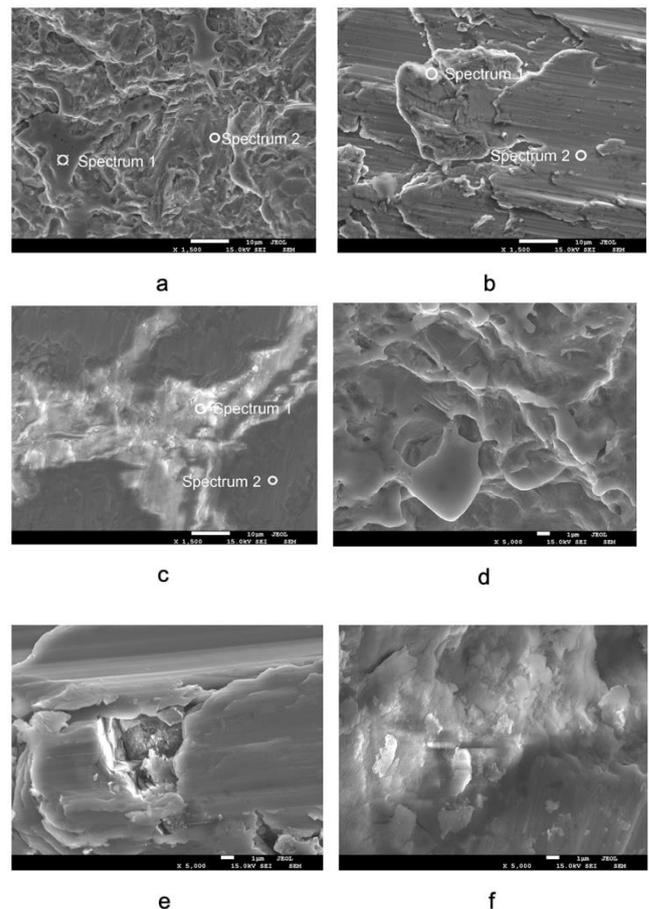


Figure 7. SEM image of a typical RBM surface of BioHorizons implants with a diagnosis of peri-implantitis, treated with: a, d – laser; b, e – diamond bur; c, f – special brush. Note: magnification x1500 (a,b,c), x5000 (d,e,f).

The RBM surface with peri-implantitis, treated with a Ni-Ti alloy brush, has its macrostructure, but has lost its microstructure, traces of micro-roughness and furrows were found on the surface (Fig. 6c, 6f). The surface was found to be highly impregnated with carbon (C) in the amount of 9.20 to 67.77 at.%, oxygen (O), and nickel (Ni) is detected in an amount from 1.09 to 2.06 at.% (Table 7). To determine the effect on the appearance of contamination of the instruments used to clean the surfaces of implants, the elemental composition of their surfaces was determined (Table 8). The general view of diamond bur and Ni-Ti alloy brushes is shown in Fig. 7. The analysis of the results of the elemental composition obtained on the surfaces of the instruments confirmed that some of the impurities present on the surface of the implants after treatment occur due to the use of bur and brushes (Table 8). After treatment with diamond

bur, diamond fragments embedded in the implant surface were detected, and carbon (C) and nickel (Ni) were found in large quantities on the surface of the brush threads.

| Spectrum | Number of chemical elements, at. % | | | | | | | | |
|-----------------------------------|------------------------------------|-------|-------|------|-------|------|-------|-------|------|
| | C | O | Na | Mg | Al | P | Ca | Ti | V |
| Laser treatment (Fig.7a) | | | | | | | | | |
| Sp1 | 2.06 | 63.08 | - | - | 3.70 | - | 7.69 | 23.48 | - |
| Sp 2 | - | - | - | - | 11.51 | 0.66 | 0.52 | 83.21 | 4.10 |
| Bur treatment (Fig. 7b) | | | | | | | | | |
| | C | O | Al | Si | S | Cl | Ca | Ti | V |
| Sp 1 | 82.15 | 3.87 | 0.88 | 0.37 | 1.93 | 1.56 | 0.51 | 7.87 | - |
| Sp 2 | - | - | 10.57 | - | - | - | - | 85.89 | 3.54 |
| Special brush treatment (Fig. 7c) | | | | | | | | | |
| | C | O | Na | Mg | Al | P | Ca | Ti | V |
| Sp 1 | 22.78 | 54.38 | 0.78 | 0.32 | - | 9.55 | 11.87 | 0.31 | - |
| Sp 2 | 8.50 | - | - | - | 10.63 | - | 0.74 | 76.65 | 3.48 |

Table 7. Elemental composition of the spectra obtained on the RBM surface implants.

| Spectrum | Chemical elements, at. % | | | | | |
|----------|--------------------------|--------|-------|-------------------|-------|-------|
| | C | Ni | C | O | Ti | Ni |
| | Diamond bur | | | Ni-Ti Alloy Brush | | |
| Sp1 | 100.00 | | 20.97 | | 38.84 | 40.18 |
| Sp 2 | | 100.00 | 24.38 | 17.64 | 29.42 | 28.56 |

Table 8. Elemental composition of the spectra obtained on the surface of the instruments.

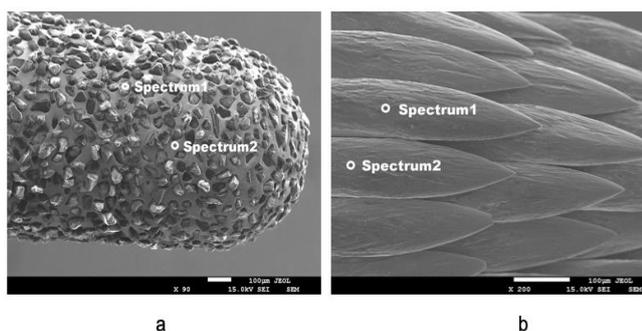


Figure 8. General view of the instruments: a – diamond bur; b – Ni-Ti alloy brush
 Note: magnification x90 (a), x200 (b).

The analysis of the obtained results of cleaning the implant surfaces showed that all types of surfaces follow the same pattern. So, the control implant already has minimal contamination. The implant with peri-implantitis has very serious surface contamination, but after laser treatment, the chemical composition of the surface completely corresponds to the composition of the control implants, regardless of

the type. Mechanical cleaning with bur or a brush also leads to complete cleaning of impurities, but energy-dispersion microanalysis showed the presence of chemical elements on the surface of all types of implants that are part of the alloy of the brush or bur. Bur treatment has a more aggressive effect, which leads to a change in the morphology of the implant surface and the introduction of rather large diamond particles into the surface of all the implants studied. Despite the literature sources that give the information about the effectiveness of cleaning the surface of implants with a titanium brush, in this study, we did not get a clean surface declared by the implant manufacturer after applying the brush. It should be noted that the literature resources give the information about fundamentally different studies and methods¹¹. There are many studies confirming the effectiveness of the laser in the treatment of peri-implantitis^{4,5,7}. In our study, we obtained results on the sparing effect of the laser on the implant microstructure and a high degree of surface cleaning. No such studies have been found in the literature, the current research is fundamentally different and requires further research.

Conclusions

1. The use of diamond burs for cleaning the implant surface in the diagnosis of peri-implantitis is doubtful in terms of effectiveness, since the surface morphology and anatomy of the implant are completely lost, and significant impregnation with carbon (C) occurs. Breaking away from the bur's surface, diamond particles are embedded in the surface of the implant.
2. The use of a special Ni-Ti alloy brush allows to preserve the macrostructure of the implant surface and effectively clean it from organic contaminants. However, the elemental composition of the surface after cleaning is significantly contaminated with carbon (C), nickel (Ni), a small admixture of sulfur and zinc was detected. This indicates the migration of elements during brushing.
3. The use of the Er; Cr; YSGG laser with a wavelength of 2780 nm preserves the macrostructure and partially the microstructure of the implant surface. At the same time, there is a complete cleaning of organic contaminants and the surface element composition becomes close

to the composition of the surface of the control implants.

Thus, laser exposure not only allows to decontaminate the surface from bacteria, but also to clear it of inclusions that can induce an immune response from the body, which, in turn, can affect the unfavorable prognosis of peri-implantitis treatment, which requires further research.

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Declaration of Interest

The authors report no conflict of interest.

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