COMPARATIVE ANALYSIS OF THE SURFACE PROPERTIES OF DIFFERENT DENTAL IMPLANTS

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Since they have a substantial impact on the implant's osseointegration, longevity, and long-term success following surgery, the surface characteristics of dental implants have drawn a lot of attention. Since titanium and its alloys are regarded to be non-toxic and to have the best biocompatibility when compared to stainless steel and cobalt-chromium alloys, which can cause allergic or cytotoxic reactions in humans, most dental implants are made of titanium and its alloys. Comparative study of the surface characteristics of three distinct titanium or titanium alloy dental implants was the aim of this project. Therefore, the elemental chemical composition of the dental implant surfaces under inquiry was ascertained by measurements made using EDS spectrometry. Additionally, measurements using scanning electron microscopy were used to highlight the surface morphology, measurements using profilometry were used to determine roughness, and measurements using contact angles were used to evaluate wettability. The results revealed that the implant with a porous structure and open micropores on the surface has the proper roughness and contact angle values necessary for good osseointegration.

Keywords: dental implant, surface properties, morphology, profilometry

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1. Introduction

The surface characteristics of dental implants have drawn a lot of attention due to the quick development of medical technology and materials used in implantology. These characteristics have a major impact on the longevity, osseointegration (the integration of the implant with the bone), and long-term success of the surgical surgery. Comparing various dental implant surface types is crucial for treatment optimization and better patient outcomes [1-3].

It has been noted that titanium and its alloys are regarded as non-toxic in the dental materials sector, with optimal biocompatibility compared to cobalt-chromium alloys and stainless steel, which can lead to cytotoxic responses or allergies from the human body [4-5]. The role of surface properties has gained particular importance since the 1980s, when Albrektsson et al. introduced the concept of osseointegration, attributing a potential role to surface properties in the biological response to an implant [6,7].

The main reasons for using titanium alloys in dentistry are their excellent corrosion resistance and biocompatibility. It is well known that, under normal atmospheric conditions, the surface of titanium is covered with a layer of oxide of TiO_2. Titanium has a relatively low modulus of elasticity, and a lower tensile strength compared to other biocompatible alloys. In the process of designing implants, it is essential to avoid sharp corners or thin sections in stress-loaded areas and to consider the possibility of shear conditions arising. The modulus of elasticity of titanium is considered to have a value approximately five times greater than that of compact bone, highlighting the importance of the correct geometric shape in the distribution of transferred mechanical pressure.

Currently, four types of unalloyed titanium and several types of titanium alloys are present. The most well-known and frequently used titanium alloy is the titanium-aluminium-vanadium alloy. At first, the treatment of the implant surface was not a major priority, but it was later successfully demonstrated that applying various treatments improves tissue integration. Thus, we have the following types of surfaces for dental implants [2,8-11]:

- Mechanical processing, characteristics of the first types of implants;
- Acid etching, which increases surface roughness to ensure better osseointegration. Acid etching can be preceded by sandblasting with fine particles.
- Sandblasting with abrasive particles, after mechanical processing, the implant is sandblasted with a material that can later be removed with a solvent, resulting in an irregular and rough surface, favorable for osteointegration;
- Porous titanium coating (TPS, Titanium Plasma Spray), the titanium liquefied through plasma is sprayed onto the surface of the implant after

mechanical processing, forming a typical layer of 20-30μm thickness and roughness of approximately 15μm;
- Hydroxyapatite coating, hydroxyapatite is sprayed onto the surface of the implant, creating a rougher surface;
- Microspheres coating, the surface of these implants stimulates faster bone proliferation and improved osteointegration.

The surface characteristics of the implant are essential for its short-term and long-term success [12,13]. Surfaces with micro-roughness promote better bone integration, providing more extensive contact between bone and implant, while also influencing the mechanical properties of the interface, stress distribution, and bone remodelling. In contrast, smooth surfaces can lead to bone resorption and the formation of a layer of fibrous connective tissue. The modification of the surface roughness of the implant has a significant impact on the cellular response by increasing the contact area between the implant and the bone, thereby improving cell adhesion to the implant. These modifications can be achieved by optimizing micro-roughness (through sandblasting, and acid etching) or by applying bioactive coatings (such as layers of calcium phosphate, bisphosphonates, and collagen) [14-16]. Additionally, wettability and surface energy highlight the surface's ability to adsorb organic molecules such as proteins, a capacity that is directly related to biocompatibility. Many studies have shown that there is a correlation between the surface roughness values of the implant and the bone-implant interface. It is believed that surfaces with higher surface roughness values generate better osteointegration than smooth surfaces. Anyway, the optimal combination of methods for modifying the implant surface that would yield the best results has not yet been established [17].

2. Materials and methods

The objective of this work was the comparative analysis of the surface properties of three different dental implants made from titanium or titanium alloy. (Ti6Al4V). The surface treatment applied for Implant 1 was sandblasting with large particles followed by acid etching, for Implant 2 it was sandblasting with large particles, and for Implant 3 the surface treatment involved active calcium ions coatings - Xpeed®.

In the study, not only an analysis of the elemental chemical composition at the surface was achieved, but also a comprehensive analysis of surface properties, namely topography, roughness, and wettability. Thus, EDS spectrometry measurements were carried out to identify the elemental chemical composition of the investigated dental implant surfaces, as well as scanning electron microscopy measurements to highlight the surface morphology, profilometry measurements to determine roughness, and contact angle measurements to assess wettability. In the comparative evaluation of the surface properties of dental implants, the most effective solutions can be identified, which lead to improved clinical outcomes and increased patient satisfaction. The dental implants evaluated in this study are presented in Table 1.

Table 1

Samples	Diameter (mm)	Length (mm)
Implant 1 (Company 1)	4.1	10
Implant 2 (Company 1)	4.1	12
Implant 3 (Company 2)	3.75	13

2.1. Dental implants characterization

The morphology of the investigated dental implants was made using an electronic microscope type XL-30-ESEM TMP F. The microscope is equipped with an EDAX-type device, which performs qualitative and quantitative compositional analyses and the distribution of the elements in the analysed sample on its entire surface.

2.2. Surface properties of the investigated dental implants

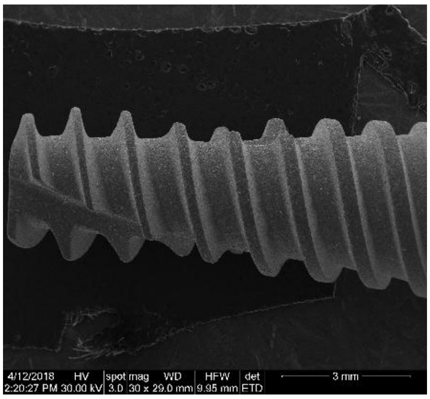
Using a Form Talysurf® I – Series PRO Range tool from Taylor Hobson Ametek, the dental implants' *surface roughness* was created. Metrology 4.0 software and a transducer with a 2 μm radius diamond tip are used by the apparatus. The measurements were made according to ISO 21920. Based on five determinations, the Ra parameter was obtained, the arithmetic average deviation from the mean line.

Using water as a wetting agent and the Krüss Drop Shape Analyzer-DSA100 instrument, the *contact angle* values were determined.

3. Results and discussions

3.1. Dental implants surface characterization

The overview and detailed images of the experimental samples are presented in Figs. 1-3. These images highlight the design of the implants, in the screw form, and differences that occur at the micro level due to the surface modification methods used.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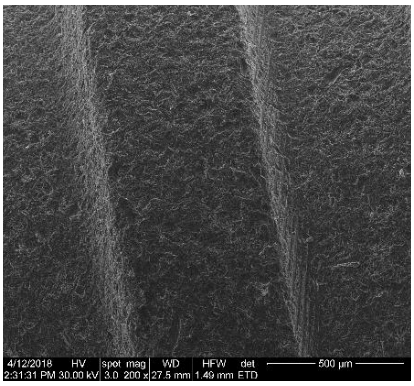
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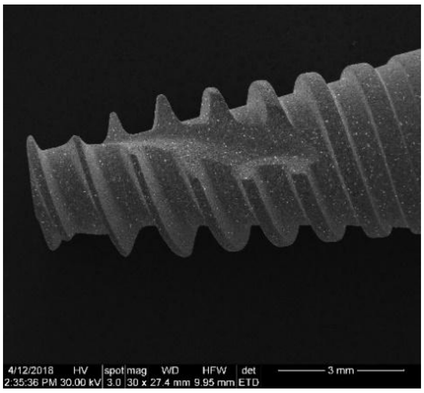
Figure 1. Overview images of the dental implant 1 surface (a); Detail image of the dental implant 1 surface (b).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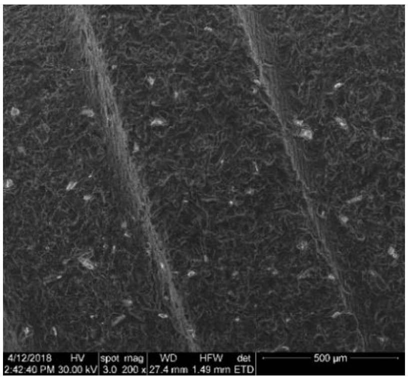
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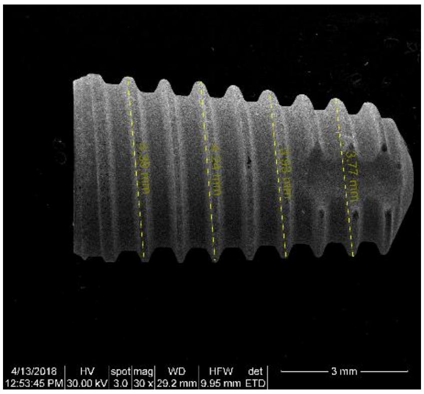
Fig. 2. Overview images of the dental implant 2 surface (a); Detail image of the dental implant 2 surface (b).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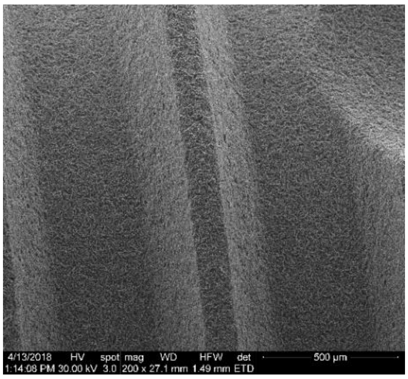

(b)

Fig. 3. Overview images of the dental implant 3 surface (a); Detail image of the dental implant 3 surface (b).

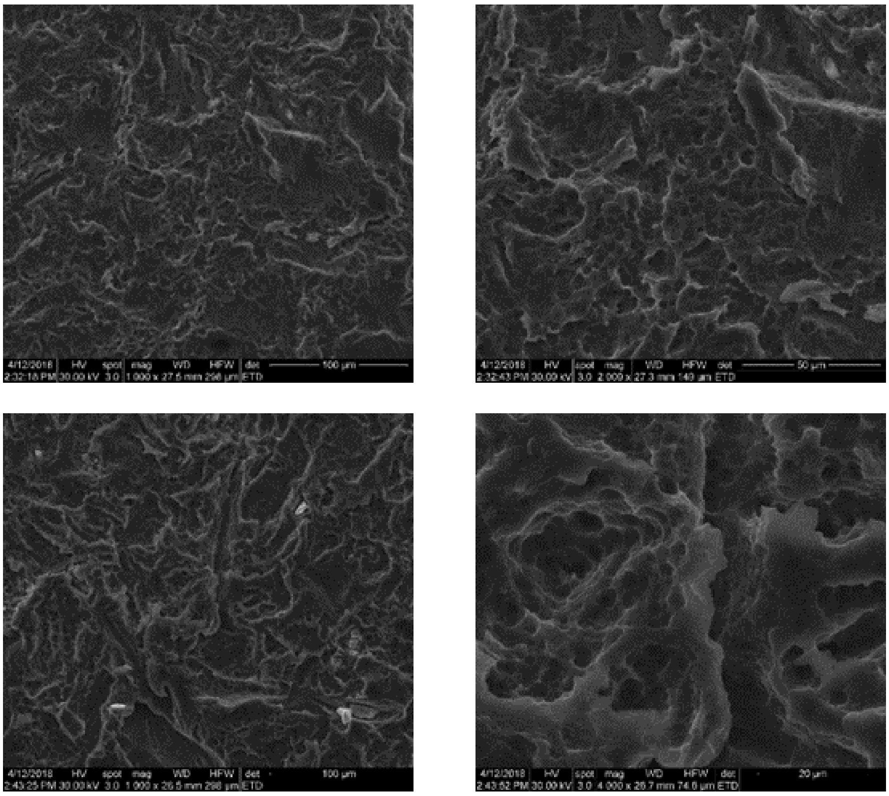
The surface morphology of the experimental samples (Fig. 4), highlighted at different magnifications, shows much rougher surfaces for dental Implant 3 made of titanium.

The morphology of Implant 3 showed a porous structure with opened micropores in the surface induced by the surface treatment with active calcium ions Xpeed®. The sandblasting with large particles applied in the case of Implant 2 as well as sandblasting with large particles followed by acid etching applied for Implant 1 generated less rough surfaces.

Following the analyses carried out using the EDS spectrometry (Fig. 5), it was observed that dental implants 1 and 2 are made of Ti6Al4V alloy, while dental Implant 3 is made of pure titanium. The EDS spectrum of Implant 3 highlighted the presence of calcium ions because of the special XPEED® surface treatment applied to its surface.

Implant 1

Implant 2



Implant 3

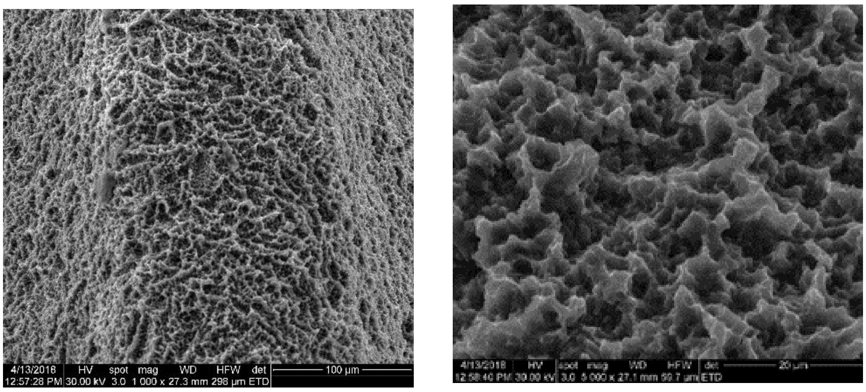
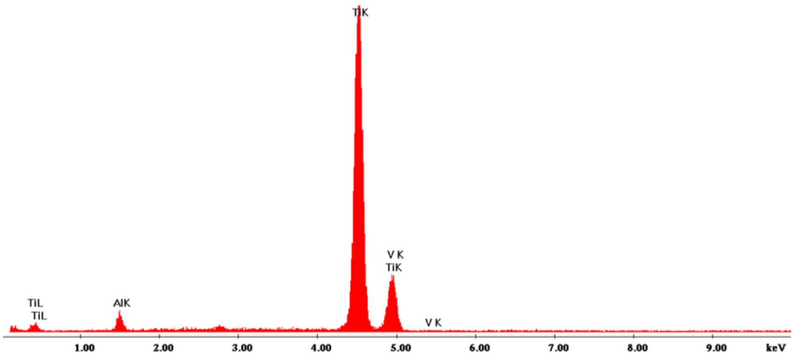
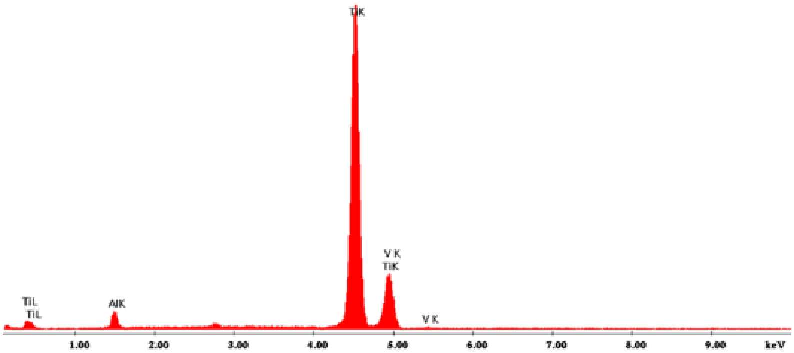


Fig. 4. Scanning electron microscopy coupled with EDS spectrometry results on the surface of experimental samples.

Implant 1



Implant 2



Implant 3

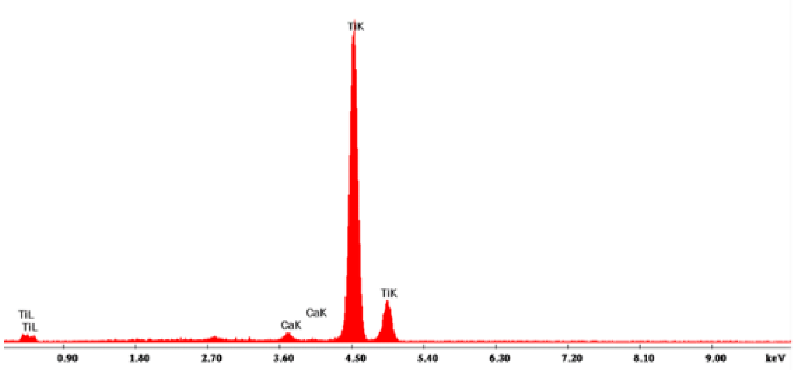


Fig. 5. EDS results on the surface of experimental samples.

3.2. Surface properties of the experimental samples

Roughness

When discussing the integration of an implant in the human body, one of the parameters that must be taken into consideration is roughness. This has a direct influence on cell proliferation and adhesion of materials, as well as osseointegration [18-21]. The results are presented in Fig. 6 and Fig. 7.

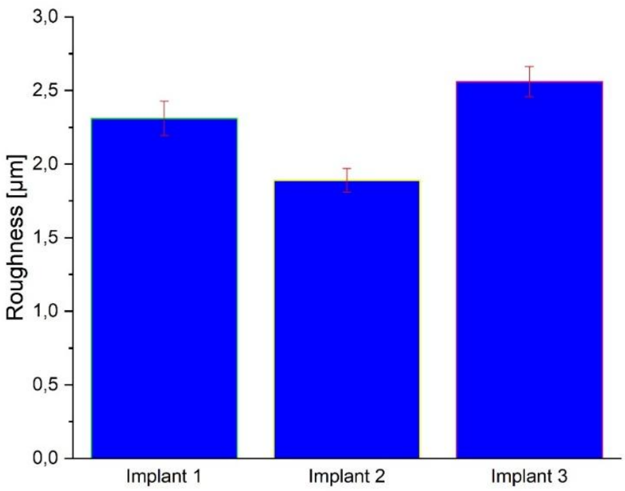


Fig. 6. R_a parameter for surface roughness of the experimental samples.

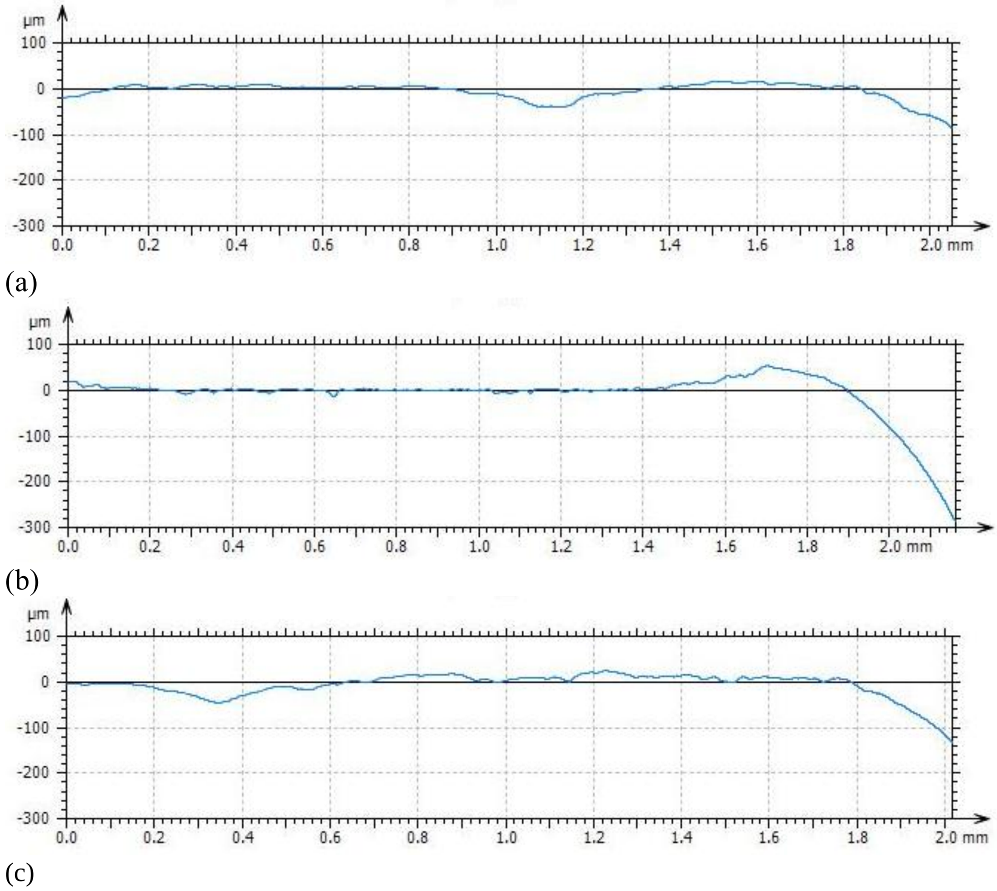


Fig. 7. Representatives roughness profiles for (a) Implant 1; (b) Implant 2; (c) Implant 3.

Our results revealed that dental Implant 2 had the lowest value of Ra (1.89 µm). Dental implants 1 and 3 obtained higher values of Ra, 2.31 µm and 2.56 µm, respectively.

Literature studies have shown that to obtain good osseointegration of the implants, they must have open micropores on the surface and roughness values in the range of 1-2.5 µm [22,23]. In the micropores existing on the implant's surface osteoblasts and the supporting tissue can migrate, increasing their bioadhesion. In terms of roughness values obtained on the investigated experimental samples are in good agreement with the specialized literature.

Contact angle

The contact angle determination is useful to establish whether the surface of the dental implant can be considered a suitable environment for an appropriate biological response. Higher levels of hydrophilicity on surfaces lead to increased adhesion and cell proliferation, which improves implant osseointegration. Fig. 8 shows the graph of contact angle values when water is used as a wetting agent.

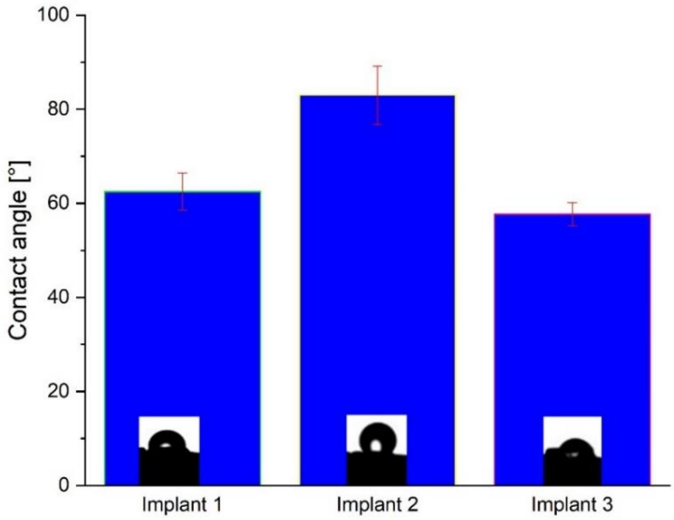


Fig. 8. Contact angle values of the experimental samples.

The contact angle value for Implant 2, whose surface was sandblasted with large particles, was 83°. Implant 1 exhibited a decrease in contact angle value to 62.5° following the application of an additional acid etching technique, whereas Implant 3, whose roughest surface resulted from treatment with active calcium ions, had the lowest contact angle value of 57.7°. According to the results obtained by applying the treatment with active calcium ions, the character of the surface is more hydrophilic. Also, by applying the additional acid etching treatment (Implant 1) the wettability is improved.

A link between the surface roughness and the contact angle value is provided by the Wenzel model [24]. This indicates that a decrease in contact angle values will result from increased roughness on hydrophilic surfaces.

4. Conclusions

The results revealed that the type of treatment applied on the implant surface influences not only the morphology but also the wettability of the surface. From the roughness point of view, the values obtained on the investigated experimental samples are in agreement with the specialized literature regarding the integration of an implant in the human body.

In terms of wettability, the best surface preparation treatment, as assessed by contact angle measurement, is with active calcium coating, followed by sandblasting plus acid etching treatment. The implant prepared with the help of this treatment has an adequate roughness value, with open micropores on the surface, necessary for good osseointegration.

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