Identification of Technological Processes of Surface Treatments for Dental Implants

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***Abstract* – The dynamics of research and science development mark every area of life. Current knowledge has a constantly expanding character, which is also provided thanks to ensuring the interdisciplinary nature of individual areas. The basic prerequisite for progress in the field of development of science and technology with an interdisciplinary character is the conformity of partial attributes and components. The field of engineering and medicine is one of the exemplary fields in which interdisciplinary is implemented daily. One such interpretation is the investigation of the possibilities and implementation of surface treatment of dental implants, which includes the knowledge of the combined field of bioengineering. The presented article is focused on the identification of technological operations of surface treatments for dental implants, specifically with the specification of additive and subtractive methods. The article identifies basic technological processes followed by a summary of the analyzed results.**

***Keywords* – surface treatment, technological process, dental implants.**

1. Introduction

The last decades have seen a significant increase in the field of medicine in cooperation with the revolution of science and technology.

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It is possible to observe an increasing dispersion of engineering implementations in the field of medical sciences, specifically in the field of prosthetics or dentistry. Current studies confirm the importance of the cooperation of these important branches through research and development of new materials, technologies, as well as production procedures, and solutions to emerging problems. Dental implantology is one of the areas that include the combination of technical fields and fields of material engineering in inclusion with medical practices [1].

Dental implantology deals with the introduction of a biocompatible material onto the surface of the bone or into the bone of the upper or lower jaw, its maintenance in this environment, and the production of specially designed fixed and removable dental prostheses, designed to restore the function of the teeth and to return the comfort and original appearance of partially or completely edentulous patients [2].

The most significant breakthrough in the field of dental implantology was provided by the Swede Per-Ingvar Brånemark. In 1952, while studying blood cells, he accidentally discovered a phenomenon that subsequently became a basic principle in all dental implantology. This is the so-called osseointegration. Brånemark was also the first to try introducing titanium-only screw dental implants, first to dogs and then to his patients. It was not until 1977 that he informed the professional public about the excellent results achieved by his implantations [3], [4].

There are many implant systems in the world that try to create such an element that would prevent possible bone loss and promote the healing of the implant. Currently, there is a large range of dental implants, which can be classified mostly according to the attraction to the environment of the oral cavity [5]:

- Closed;
- Semi-closed;
- Open.

In addition to the above classification, dental implants can also be classified according to the aspect of compatibility with living tissues [6]:

- Biotolerant - they are tolerated by the tissues, when connected, fibrorointegration occurs mainly;
- Bioinert - they are fully acceptable by the tissues, osseointegration occurs when connected;
- Bioactive – they evoke osteoconductive processes in tissues, physical-chemical connection, and biointegration occurs when connected.

Surface roughness and chemical composition of the surface are among the properties of the surface of the implanted prosthesis, which very significantly influence the degree and quality of osseointegration of dental implants. The implanted material should not contain elements or compounds that reduce its biocompatibility and have an adverse effect on the human body. The goal of implant integration is the formation of a calcium phosphate layer on its surface. The formation of this layer is influenced by the chemical composition of the surface of the dental implant. The presence of hydroxyl groups, which ensure a hydrophilic surface, has a positive effect [7], [8].

Dental implants can be distinguished most often by the material they are made of, the shape they are molded into, and the surface treatment that ensures their desired properties. This article deals with the issue of technological operations for the surface treatment of dental implants.

2. Technological Operations of Surface Treatment of Dental Implants

From the point of view of the technology used to achieve the desired properties of the material, the surface treatment of implants is classified into two basic methods [9]:

- Subtractive method
- Additive method

❖ Subtractive methods

Methods that eliminate microscopic particles from the surface of the implant and give rise to an irregular morphology of the titanium surface are called subtractive methods and include for example acid etching, sandblasting, chemical acid etching, and etc. Subtractive methods increase the surface area of the implant without contaminating commercially pure titanium from added particles. The probability of contamination or dispersion of microparticles into the surrounding tissue is very low.

❖ Sandblasting

This technology creates surface macro-roughness with a magnification of about 10 times and uses e. g. Al_2O_3, TiO_2, ZrO_2, or calcium phosphate powder, while the grain size of the material used has a greater influence on the final effect than its type. The most suitable size is 180 to 220 μm, particles above 300 μm no longer lead to a further percentage increase in the contact between bone and implant. It is also necessary to consider the possible influence on the accuracy of the thread due to the influence of the abrasive. The disadvantage of the method remains the risk of contamination by abrasive particles, however low this risk may be. Removing all abrasive residues is not always easy and soaking in acid is mainly used for this. The resulting roughness of the surface depends on the material used, the size and shape of the particles, the applied pressure, but also on the time of sandblasting, the distance of the implant from the nozzle, etc. The surface of the material is irregular, consisting of depressions and pits of various sizes (Figure 1) [10], [11].

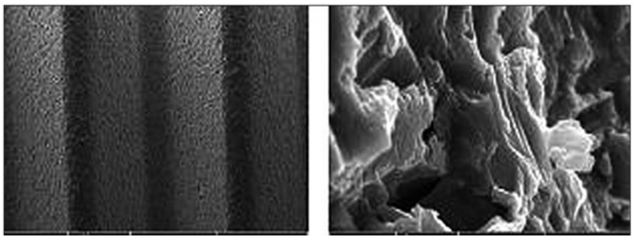

Figure 1. The surface area of titanium implant sandblasted with TiO2 particles - Scanning Electron Microscopy, magnification 100 (left) and 7500 (right) [11]

❖ The acid in mineral etching

The effect of the chemical creates a micro-roughness of the implant surface in the range of 1 to 10 μm with concave irregularities. These dimensions are favorable because the bone mass penetrates well into irregularities with a diameter of 1 to 2 μm. Etching is done in either hydrochloric acid (HCl), hydrofluoric acid (HF), or sulfuric acid (H2SO4). It can be used on a machined surface or on an already-treated surface. It also appears advantageous that thanks to the chemical modification, a hydrophilic surface of the implant is created, which is more suitable than a hydrophobic one in terms of interaction with the surrounding tissue [10], [11].

❖ Alkaline treatment of surface

Alkaline treatment ensures a bioactive apatite layer on the surface of the implant, which can already be prepared by e.g. sandblasting or preparation in a boiling Ca $(OH)_2$ solution. The implant prepared in this way is immersed under physiological conditions in a Simulated Body Fluid (SBF) or a Supersaturated Calcium Phosphate Solution (SCPS) [12].

❖ Anodic oxidation

The process of surface treatment takes place electrolytically in an environment of strong inorganic (mineral) acids and leads to the strengthening of the oxide layer with the formation of micro or nanopores, depending on the concentration of the acid used and the density, composition, and temperature of the electrolyte. A great advantage is the possibility to influence the thickness of the oxide layer by the technological procedure used. Anodic oxidation is implemented as a standard, for example, for surface treatment of TiUnite dental implants (Figure 2) [13], [14], [15].

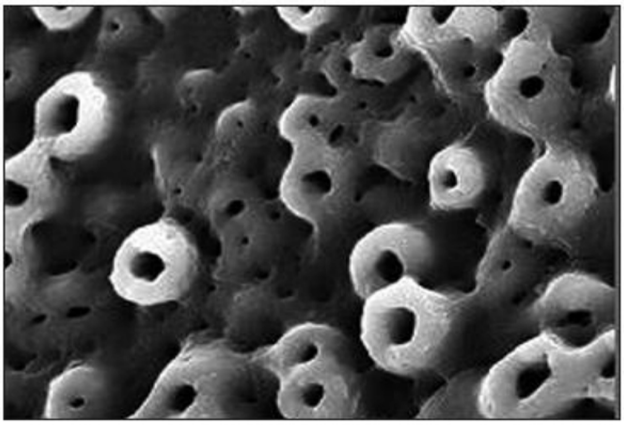

Figure 2. Application of anodic oxidation on the surface of dental implant TiUnite – Scanning Electron Microscopy, magnification 1400 [15]

❖ Fluoridation

By the action of hydrofluoric acid on the surface of the implant, fluoride ions are added, and it is possible to achieve not only a microstructured but also a nanostructured surface. Surfaces enriched with fluoride ions have greater bone-to-surface contact. Fluoride ions also change bone apatite to fluoroapatite and increased differentiation of osteoblasts is seen, e.g. Osseo Speed^{TM} surface (Figure 3) [11], [16].

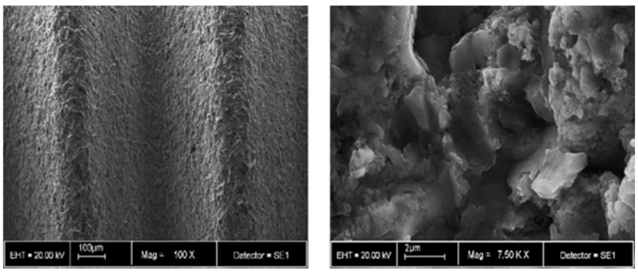

Figure 3. Surface of dental implants (Osseo Speed^{TM}) after the fluoridation - Scanning Electron Microscopy, magnification 100 (left) and 7500 (right) [11]

❖ Additive methods

Additive methods are methods that use the gradual addition (layering) of material to the surface of implants (application of hydroxyapatite or titanium particles using plasma spraying). The aim is to improve the biological and physical properties of the implant surface, which is in direct contact with the bone [17].

There are many techniques used for surface treatment, but they do not always result in a clean and even surface. The long-term stability of these modifications and their resistance to corrosion (e.g., in the case of an implant surface coated with hydroxyapatite) can also be a problem, as well as easier plaque retention in places where the implant surface is exposed [18].

❖ Titanium Plasma Spraying

Titanium Plasma Spraying (TPS) (Figure 4) achieves increased roughness by adding material to the surface of the implant. This technique is based on the transfer of energy between the plasma beam and the titanium present in the protective argon atmosphere, which is subsequently melted at high temperature and entrained to the surface of the implant in a thickness of about 30 to 40 µm. However, compared to other surfaces, titanium particles are more easily released from the modified surface, e.g. due to friction during the insertion of implants, and these particles can then be found in the newly formed bone matrix and, to a greater extent, in the bone marrow [11], [19].

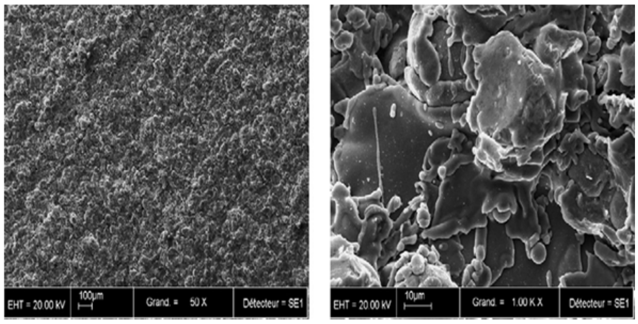

Figure 4. Dental implant surface after the application of titanium plasma spraying [11]

❖ Plasma spraying with hydroxyapatite

Plasma spraying with hydroxyapatite creates a layer from 50 µm on the surface of the implant. However, with a thicker layer (over 200 µm), the risk of coating cracks increases significantly while the strength decreases. Another disadvantage of a thicker layer is the possible release of coating particles from the surface of the implant, which can occur, for example, as a result of friction during its introduction. Disadvantages of plasma spraying led to the development of other methods of applying a calcium phosphate layer to the surface of the implant, such as the biomimetic surface modification or the method of applying thin layers, which make it possible to reach a layer height in the order of micrometers [20].

- Specific methods of applying microlayers

Sol-gel methods are procedures for the preparation of glassy, glassy crystalline or crystalline materials. They can be hydrolytic or anhydrous, the essence is the homogenization of the solution of the starting components into a sol, and then into a gel, while their homogeneity does not change. In dental implantology, the method is used to apply calcium phosphate in the form of thin layers, and with this treatment of the implant surface, we can achieve a layer with a thickness of 1 µm. The technique is based on the preparation of a colloidal suspension (salt) containing calcium phosphate precursors, in which the implant is immersed. Subsequently, the suspension is converted to a viscous gel and then to a solid material. The formation of the desired bioactive layer is then ensured by vacuum drying [21], [22].

Pulsed Magnetron Sputtering – the principle of the method is similar to the two previous techniques. An electric discharge is created in the vacuum, which subsequently burns in argon, and the resulting gas ions spray the particles released from the target towards the substrate. The magnetic field present causes the electrons to move along the helix, increasing the probability of ionizing additional argon atoms. The benefit of the coating method is a reduction in the thickness of the calcium phosphate coating, which leads to a significant elimination of the risks associated with the appearance of a defect on the surface of the implant, especially after it has been loaded. It also causes a reduction of possible residual stresses that arise within a possible higher layer and could lead to cracks at the interface between the coating and the substrate [23], [24].

In principle, Pulsed Laser Deposition (Figure 5) is similar to the method using an ion beam, but the release of calcium phosphate from the target occurs after the impact of the laser beam. Everything happens in a vacuum, and the resulting plasma cloud subsequently falls on the surface of the implant, where it condenses, thereby achieving the required thin layer on its surface.

The disadvantage of the technology can be the formation of small droplets causing inhomogeneity of the surface, and the fact that without suitable heating of the substrate, a crystalline apatite layer will not be formed, but only an amorphous layer on the applied surface [25].

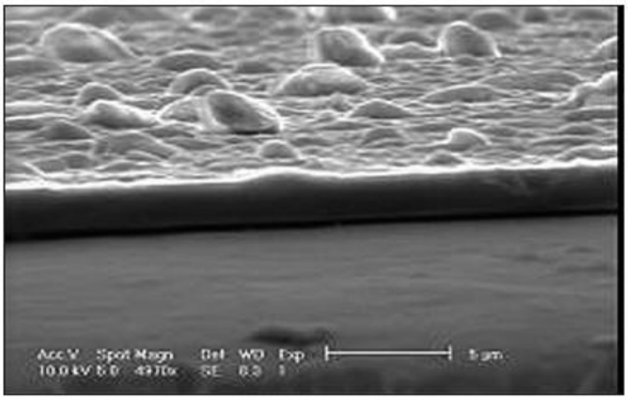

Figure 5. Image of a cross-section of a dental implant coating created by pulsed laser deposition technology [26]

3. Conclusion

In the creation of medical products, especially with application in the human organism, the synergy of the interdisciplinary nature of scientific fields is essential. In addition to the basic and primarily considered medical point of view, the point of view of bioengineers or material engineers also plays a very important role. This article is focused primarily on pointing out the possibility of synergy between the mechanical engineering industry and medical sciences, specifically with a focus on identifying the possibilities of surface treatment in the production of dental implants. Based on the overview, a basic summarization (Table 1) identifying the knowledge gained was created.

Table 1. Short summarization

Implemented method of surface treatment	Aim of implementation
Sandblasting	Increase in biomechanical fixation of the implant
The acid in mineral etching	Removal of oxide scales and contamination
Alkaline treatment of surface	Improvement of biocompatibility and bioactivity
Anodic oxidation	Formation of specific surface topography; Corrosion resistance
Fluoridation	Increase in hydrophilicity and overall improvement of osseointegration
Titanium Plasma Spraying	Pressure reduction at the bone-implant interface
Plasma spraying with hydroxyapatite	Improved wear resistance, Corrosion resistance
Sol-gel methods	Improvement of biocompatibility and bioactivity
Pulsed Magnetron Sputtering	Supporting bone material ingrowth and remodelling
Pulsed Laser Deposition	Non-contact and elimination of implant contamination

The achieved surface treatment is subsequently put to a series of tests with the implementation of methods aimed at determining the degree of adhesion, monitoring the topography of the surface, and etc. The identification of test methods after the implementation of surface treatments of dental composites is the subject of further analysis for subsequent scientific and technical articles.

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