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RESEARCH ARTICLE

Abrasion-Resistant Elastic Coatings Technology for Dental Implants

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Abstract

Development of coatings with the properties of resistance to mechanical loads of various kinds as abrasion, pressure remains an urgent issue in modern dentistry. A framework with a stable coating is less exposed to an aggressive biological environment - saliva, as well as the activity of microorganisms. To achieve the optimal result, it is necessary to search for the optimum in a combination of three factors: the actual structural properties of the implant, the properties of the coating of the implant, as well as the manufacturing technology of the coating and the implant itself. The work was performed on a clinical basis of Federal State Autonomous Educational Institution of Higher Education I.M. Sechenov First Moscow State Medical University of the Ministry of Health of the Russian Federation (Sechenov University). Medical steel, grade BioDur 108 (Carpenter Technology Corp.) was used as the basis (or substrate) for production of dental implants for testing. Supporting coatings based on titanium oxide (TiO_2) or based on titanium nitrides/oxynitrides (TiO_xN_{1-x}) were placed on the substrate. Roughness coefficient (R_a) was in the range of 0.30-0.55 µm. We have not recorded statistically significant differences between the R_a value and type of product (substrate). That is, dental implants with and without coating did not have a difference in the R_a coefficient. The same results were obtained for the hydrophilic properties of the surface of dental implants - regardless of the presence or absence of coating, hydrophilicity indices were observed within 84-87%. The surfaces of dental implants do not have a significant effect on any physiological indicators of platelet activity. Without contact with the substrate, the parameters of blood plasma were proved to remain unchanged for an hour at 37°C. On the contrary, in contact with the steel part of the dental implant, without coating, there was a significant increase in platelet activity. As our experiments showed, the presence on the dental implants of a coating consisting of titanium oxide, or with the inclusion of Ti-O-N, reduces the likelihood of a blood clot. The reason for this is reduced adhesion of blood cells to titanium oxide surfaces.

Keywords: *Magnetron sputtering apparatus, Titanium oxide, Spearman correlations.*

Introduction

The installation of dental implants is one of the advanced technologies in 21st century dentistry. The most urgent issue in modern dentistry remains the development of coatings having the properties of resistance to mechanical loads of various kinds-abrasion, pressure, etc. [1, 2]. The combination of these two areas, of course, helps to improve the quality of the implant as a whole. A framework with a stable coating is less exposed to an aggressive biological environment -saliva, as well as the activity of microorganisms [3]. Also, with a stable coating, the effect of mechanical abrasion, pressure arising during chewing, as well as enamel cracking, which can occur with sharp temperature drops when taking hot and cold food, is minimized. Thus, to achieve the optimal result, it is necessary to search for the optimum in a combination of three factors-the structural properties of the implant proper, the properties of the implant coating, as well as the production technology of the coating and the implant itself [4, 5]. Among the various options, the combination of a material compatible with tissues and a certain bio inert coating is recognized as the most effective.

Such an implant should have high resistance to stresses resulting from chewing. A mandatory property of the second component, the coating, is its biological inertness. This implies its integration into bone tissue, as well as an increase in the period of guaranteed use [6]; the implant should not cause local reactions. One of the main requirements is the surface structure of the product, while taking into account such characteristics as roughness, layer thickness and other morphological parameters, as well as mechanical properties-wear resistance, resistance to friction, pressure, exposure to different temperature conditions and chemically active substances contained in the oral cavities and in incoming food [7].

Another of the mandatory properties of the coating, as well as the implant itself, is a reduced or absent immune response to it from the body, the prevention of cases of possible rejection or allergic reactions and autoimmune diseases. Among many materials in modern dental practice, preference is given to titanium or alloys with its participation [8, 9].

Titanium is capable of forming a thin oxide layer on the surface of the implant. Moreover, if titanium itself has good adhesion indicators (i.e. integration with bone tissue), the formation of an oxide film promotes the chemical inertness of the dental implant, as well as the appearance of dielectric properties [10, 11]. The latter can prevent possible pathologies of galvanic origin.

This work is dedicated to solving one of these issues, namely, the properties of the coating of dental implants. The purpose of this study is to compare and develop a coating for dental implants that are resistant to mechanical stress. The tasks included: a) testing for mechanical (abrasion, pressure) and physical strength of different coatings of dental implants; b) to test the hydroxyapatite coatings proposed in this work.

Material and Methods

The study was performed on the basis of Institute of Dentistry of I.M. Sechenov First Moscow State Medical University (Sechenov University) Moscow, Russian Federation. For production of dental implants for testing, medical steel, grade BioDur 108 (Carpenter Technology Corp.) was used as the basis (or substrate).

Titanium oxide based coatings (TiO_2) were placed on the substrate, or based on titanium nitrides/oxynitrides (TiO_xN_{1-x}). Dimensional characteristics of the product: 1 cm each of the 4 sides of the square, with a layer thickness of 0.1 mm. The formation of a smooth surface of the product was carried out using a magnetron atomizer electrode based on titanium, while the value of R_a did not exceed 0.01 µm. Processing was carried out in two gas mixtures, namely: oxygen-argon, oxygen-nitrogen. Films were produced using a medium-frequency magnetron sputtering apparatus. At the same time, the following parameters were adhered to: target-Ti, O_2 pressure 10^{-1} MPa, electric discharge voltage 350 V, current 2.5 A. Processing periods was 1.5 hours.

For the coatings obtained, the friction coefficient (from 0.2 to 0.23), the elastic recovery coefficients (77%) and the wear resistance (up to 9.6 $mm^3/H*m$) were measured. Surface roughness of the film was measured with the use of Talysurf 5-120 system (Taylor-Hobson, United Kingdom, resolution up to 10 nm). In this case, R_a was recorded as the average deviation of the profile for 1.5 mm length.

The electrical parameters of the tested products were also measured using the measurement of the difference in the potentials of the measured objects (weak potential) and the potential of a person's bioelectric field that exceeds them. In addition, using the Easy Drop DSA 20E apparatus (manufacturer country-Germany), such an indicator as surface wettability was evaluated.

Wettability refers to the hydrophilic and hydrophobic properties of the test film. Studies were carried out at the following indicators: temperature 27±2C, humidity 50±7%. The second part of the experiments is related to measuring changes in platelet activation in blood plasma. For this, blood plasma was first released in vitro. Selection was carried out on a voluntary basis in a healthy person, platelets-enriched while samples were selected.

The obtained samples were centrifuged (g=250), the centrifugation time was 5 min. After centrifugation, 1 ml of the sample was taken and placed in containers with the studied products. The incubation time was 60 min; the temperature was 37°C. For a negative control, a similar procedure was considered, but without the participation of implants, for a positive one - with the use of an uncoated steel substrate.

After 60 min, structural and functional changes in platelet homeostasis were monitored. Using the method of optical density, platelet aggregation activity was evaluated. To induce aggregation, ADP (or adenosine diphosphate) was used, in two concentration variants - 25 μmol/ ml and 50 μmol/ ml.

Also, when assessing structural changes, we used a method for determining the platelet aggregation degree (given in %). Statistical data processing was performed using the Past v. 3.0. The data obtained are primarily checked for the normality of the distribution, the results obtained indicate a distribution other than normal. In this regard, during further data processing, we used nonparametric methods of statistical analysis. The differences are significant at $p \leq 0.05$. We used the Wilcoxon T-test, as well as correlation analysis (Spearman correlations). The latter is necessary when detecting possible connections between the studied traits.

Results

Physical characteristics of the surface of the dental implant .According to the data acquired, the roughness coefficient (hereinafter in the text and tables - R_a) was in the range of 0.30-0.55 μm (Table 1). We have not recorded statistically significant differences between the value of R_a and the type of product (substrate). That is dental implants with and without coating did not have a difference in the coefficient R_a.

Table 1: Parameters of the studied TiO_2, TiO_xN_{1-x} coatings of dental implants

		Grounding Substrate			-100 V offset performance		
Model	Uncoated	TiO_2	TiO_xN_{1-x}, 50 by 50%	TiO_xN_{1-x}, 25 by 75%	TiO_2	TiO_xN_{1-x}, 50 by 50%	TiO_xN_{1-x}, 25 by 75%
Coating Thickness, nm	no	150±6	268±7	293±6	190±7	189±6	212±6
R_a	33	39±3	36±3	35±2	53±4	27±2	37±3
Nanohardness, GPa	2.2	7.2±0.3	4.4±0.3	3.7±0.3	4.2±0.3	3.6±0.3	-
Contact angle of wetting in water, degrees	87±4	91±4	106±2	112±3	97±2	95±1	95±2
Contact angle of wetting in glycerol, degrees	-	95±2	99±3	96±7	82±3	92±5	91±1
Surface energy, MJ/m^2	29±1	21±1	11±1	20±1	26±3	16±2	14±4

The same results were obtained for the hydrophilic properties of the dental implants surface - regardless of the presence or absence of coating, hydrophilicity indices were observed within 84-87%. From this we made the following conclusion - the surfaces of dental implants do not have any significant effect on any physiological indicators of platelet activity. Negative values were obtained while studying the surface potential of coated dental implants. An increase in the level of oxygen concentration was accompanied by a sharp increase in the potential amplitude. This level was exceeded more than 3 times, from -165 to -580 mV. A drop in the level of nitrogen concentration is also recorded here, in the titanium oxide film.

Our data confirm the fact that high elastic potential, as well as physico-mechanical parameters exceeding those for products without coatings are characteristic for the tested coatings. The application of a 100 V bias resulted in an increase in elasticity. Among other types of films, films of the TiO_xN_{1-x} sample showed the greatest hydrophobicity, when the substrate mode was grounded, when compared with the applied offset of 100 V .The results of the biological part of the experiment. We found that without contact with the substrate, the parameters of blood plasma remained unchanged for an hour at 37°C. On the contrary, in contact with the steel part of the dental implant, without coating, there was a significant increase in platelet activity (Table 2).

Table 2: Characterization of cell-humoral parameters for blood plasma after contact with dental implants surface

Group name	Platelet Aggregation in ADP, %	Platelet Aggregation with Collagen, %	Platelet count in plasma (g/l)	The average platelet volume, μm³
Negative control (no substrates)	76.7	80.4	372	7.0
Positive control (with substrates)	81.7±3.9	83.4±1.1	491±5	6.8±0.3
TiO_2 Coated	84.8±1.2	83.6±2.7	519±14*	6.9
TiO_xN_{1-x} Coated	83.2±2.2	83.8±0.9	511±7*	6.8±0.01

Statistically significant differences between the coating and the steel substrate at $p \leq 0.05$

These data are significant in relation to the negative control. When both types of coatings were applied, the opposite reaction was observed: a statistically significant decrease in platelet activity indices compared to an uncoated steel product. At the physiological level, there was a decrease in the rate of formation of aggregates from platelets, both in the presence of ADP and collagen.

An increase was noted in the level of concentration of cells in blood plasma, the same as a general increase in the proportion of cells in relation to the non-cellular component of blood plasma. This process can be caused by two factors: a) a decrease in the quantitative indicators of platelets in a liquid medium that directly form aggregates. b) a significant decrease in platelet adhesion indicators originating from the liquid phase with respect to the test films on the surface of dental implants.

Discussion

Among the variety of materials used in dentistry in recent decades, titanium and its alloys are becoming more widespread [12]. Titanium is most suitable for the installation of crowns and bridges, as well as for dental implants [13, 14, 11].At the same time, titanium and its alloys are characterized by a relatively low wear resistance compared to nickel alloys. However, during tests of this kind, metal particles adhere to the surface of the drill, ultimately leading to a mismatch between the calculated and real indicators.

Our works has shown that in a dental implant, the basis bearing such properties as hemocompatibility, as well as wear resistance, may not be the substrate, but the contact point itself, but the coating. At the same time, it is possible to change the properties of a dental implant, forming films of various compositions on its surface. The strength of the coating as a whole, as well as its life, will largely depend on the properties of the coating and the characteristics of its contact with food, under pressure, and in an aggressive biological environment (saliva) [15]. TiO_2 and TiO_xN_{1-x} based coatings have a high potential for mass use when installing dental implants [16, 17].

The formation of an oxide film even on a molded titanium product gives additional properties to the entire implant as a whole - chemical inertness, negative electric potential on the surface, and low probability of the body's immune response [18, 20]. In our case, the effect of the film on the properties of the entire implant is clearly demonstrated by the example of a steel product with and without coating. Thus, in the future it seems promising to develop primarily coatings, with minimal consideration for the properties of the substrate.

Conclusion

As our experiments showed, the presence on the dental implants of a coating consisting of titanium oxide, or with the inclusion of TiO_xN_{1-x}, helps to reduce the likelihood of a blood clot. The reason for this is reduced adhesion of blood cells to titanium oxide surfaces. Adhesion is manifested in connection with negative potential indicators of products with a titanium oxide film, which significantly reduces the likelihood of platelet aggregation [21].

From literature data state the two main reasons for these properties as: a) the hydrophilicity of the surface of medical implants [22]. This increases the chances of hemocompatibility. b) In direct contact with blood, a surface with a negative potential is preferred.

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