ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Formation of the Porous Structure of Material Surface Using the Method of Laser Processing.

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ABSTRACT

This article describes the theoretical research of the laser technology for the creation of biocompatible surfaces having porous structure. The specifics of the formation of porous structure when using the technologies of applying materials and composite coatings and the evaluation of the modes of the process procedure for obtaining developed surface using the method of laser processing are considered.
Keywords: titanium, endoprosthesis, porous structure of an implant, laser processing

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INTRODUCTION

Recently a number of publications on the positive results of using inorganic bioinert coating and recombinant human bone morphogenetic protein-2 (BMP-2) have appeared. This is confirmed by a new method of the formation of developed surface using laser technology, which is patented in the Russian Federation [1].

A number of scientific studies confirm that titanium and its alloys are the most promising materials for the production of implants and prostheses in terms of strength and durability [2,3,4].

The relevance of the issue is characterized by an integrated approach to the method for the formation of developed surface and applying inorganic bioinert coating and recombinant human bone morphogenetic protein-2 (BMP-2) [5,6,7,8].

In this regard, the development of the technology for the formation of developed surface of an implant, which forms a mechanically strong bond with bone tissue, is seen as promising. As a result, the developed technology should make it possible to produce implants, having improved biological compatibility.

The purpose of the scientific study is to carry out theoretical and experimental research of the laser technology for the creation of biocompatible surfaces having porous structure.

To achieve this goal, the tasks of theoretical and experimental research of the laser technology for the creation of biocompatible surfaces having porous structure were solved. One of important stages of accomplishing this task was the development of a laboratory process procedure of obtaining developed surface using the method of laser processing.

Significant disadvantages of conventional technologies of the formation of porous structure of implants are the random form of relief surface and significant variation of its geometric dimensions. This leads to the creation of different conditions for the process of osseointegration on different areas of the implant surface and, consequently, to the creation of qualitatively heterogeneous structure of the articulation of bone fragments with the implant.

The shape and size of the craters of porous surface assume great importance in case of using technologies of applying various materials, contributing to the improvement of the quality of osseointegration, on the surface of implants. The thickness of the coating layer and unevenness of its distribution may fundamentally change the conditions of osseointegration due to the change of geometric shapes and sizes of pores.

The shape and size of the pores are also important under the conditions of the use of various preparations, contributing to the improvement of the quality of osseointegration. Applying composite material to the implants contributes to the acceleration of the processes of bone tissue regeneration. According to the results of extended clinical testing, the osteoinduction of composite materials containing recombinant rhVMR equals to the osteoinduction of autologous bone material or surpasses it. As shown by the results of studies [9], composite coating with prolonged form of rhBMP-2 contributes to the increase of adhesive bonds of newly formed bone tissue with the surface of the samples as compared with the coating that doesn't contains recombinant bone morphogenetic protein. Despite the positive results of the study of bone morphogenetic proteins, a number of problems remains unsolved: the choice of an effective technology for obtaining rhVMR, the development of the prolonged form of the preparation, the choice of an appropriate biodegradable rhVMR carrier. Besides, the task of applying preparation and their uniform consolidation on the surface of an implant under the conditions of mechanical impact during installation also becomes very relevant. Its solution largely depends on the method of the processing of titanium implant surface and is related to the rational choice of shapes and sizes of pore craters in the process of the formation of the structure of implant surface. It can be assumed that even distribution of composite material on the surface will contribute to obtaining higher values of the amount of pullout force required to detach an implant from the bone.

Specifics of the formation of porous structure when using technologies of applying materials and composite coatings

Solving the tasks of the formation of quality pores with homogeneous predictable form and their layout makes it possible to create an implant forming a mechanically stronger bond with bone tissue and designed for the implantation into bone tissue, such as the surface of an orthopedic or dental implant.

The positive effect is achieved by the fact that in the implant for the implantation into bone tissue there are holes on the outer surface over the entire surface of the endosteal part of the implant, made with the step L edgewise and lengthwise, wherein the holes have a form a truncated cone, the basis of which is embedded not less than 40 microns, and the holes are made by a laser beam by rotating it through 360° at an angle α to the axis of the formed hole [1].

Surface microroughness is formed over the entire surface of the implant. The above-mentioned implant is a metal implant made of industrial pure titanium or titanium alloy. The above-mentioned implant is a dental and orthopedic implant. The essence of the proposed solution is illustrated by the general appearance of the implant surface with the transverse cut of the conical hole, which is shown in Figure 1.

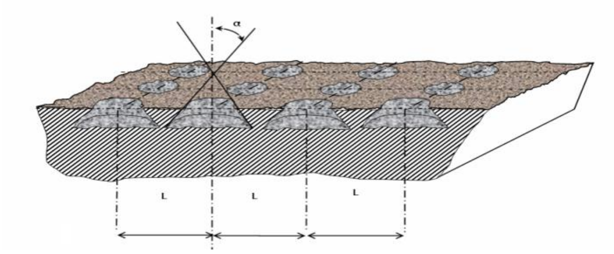

Fig.1. An implant for the implantation into bone tissue

When installing the implant into the bone bed, reliable fixation of the endosteal part is achieved as a result of forming additional force, resulting from tearing of biological tissue at the moment of physical impact and determined by the surface of osseointegration elements, made in the form of conical holes, as well as by the large area of contact with bone, resulting from the microroughness of the implant surface, when in the space adjacent to the implant mature bone structures are formed in a stage manner. Bone gradually integrates with the implant relief, which is developed to the similarity with its microarchitectonics, which results in the formation of a strong "bone-implant" bond.

A metallic titanium-based implant is suitable for the installation into bone tissue. Thus, it can be a dental implant, an orthopedic implant, etc., depending on the bone tissue, into which it is supposed to insert the implant. The specific morphology of the surface ensures the sustainable integration of bone. In case of this specific morphology the newly formed bone, which grows into the holes and irregularities of the implant surface, cannot be easily broken off from the old bone.

The introduction of this technology for the formation of porous implant structure makes it possible to get the following technical result – improved stability of implant installation, improvement of the conditions of osseointegration by providing increased contact area and thus binding between the implant and the bone tissue, resulting in an increased mechanical retention and durability, i.e. to the improved osseointegration of the implant.

Evaluation of the modes of the process procedure for obtaining developed surface using the method of laser processing

An important task of achieving a positive outcome is the evaluation of the modes of the process procedure for obtaining developed surface using the method of laser processing. Given that laser cutting of materials is characterized by the thermal effect of radiation, which causes the processes of the evaporation of material, melting, and removal of the molten material from the zone of cutting, by chemical reactions of combustion, thermal degradation, etc., the task of the evaluation of the modes of the process procedure for obtaining developed surface using the method of laser processing involves the determination of the main parameters affecting the quality of the formation of pores on the surface of implants, and the preselection of their nominal values and the limits of variation for different options.

To use the laser technology of obtaining developed surface, it is necessary to makes estimates of the threshold values of energy parameters of pulsed laser radiation.

The main parameters of lasers, which determine the quality of laser processing, are:

- radiation power P;
- wavelength λ;
- pulse length τ;
- pulse recurrence frequency f;
- spatial characteristics of the mode structure of radiation;
- beam divergence α.

The procedure of obtaining porous structure using laser is based on the analysis of hydrodynamic and thermal problem of gas laser cutting process taking into account the emergence of a wave and the removal of molten material from the zone of cutting. The interaction of laser radiation with the surface of the treated material is based on the termophysical impact, which is able to melt material, bring it to a boil and partly evaporate.

The conducted experimental research of the modes of processing of titanium implants showed the need for the application of the technology of pulse gas-laser cutting [10]. The technology with simultaneous application of laser radiation and gas jet is one of the most effective in terms of quality of materials processing. One of the main benefits of this technology is associated with the blowing of molten material from the laser beam impact zone. This contributes to the increase of the amount of removed liquid phase and makes it possible to reduce the effect of uncontrolled redistribution of the molten material at the moment of the end of the laser pulse. As a result, it seems possible to obtain surfaces with low roughness and ensure high precision of geometrical sizes of the formed pores. In the process of cutting titanium an oxygen jet is fed to the heating zone. As a result of the exothermic reaction of metal oxidation additional heat is generated, which makes it possible to significantly increase the cutting speed.

It was found that the quality of cutting is influenced by radiation power, power density, diameter, divergence and mode structure of radiation, focal length. The diagram of the process of gas laser cutting is shown in Figure 2.

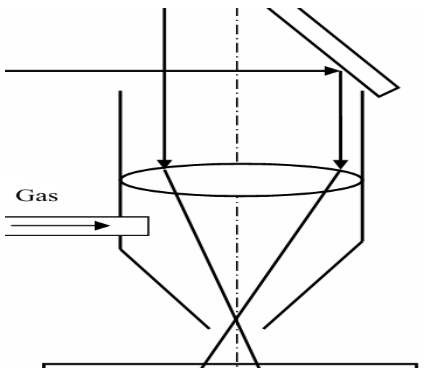

Fig.2. Diagram of the process of the formation of pores on the surface of an implant

Laser radiation is fed to a defocusing lens. The focal plane of a beam is above the surface of the implant. As a result, the major part of laser energy is distributed in the material in the form of a truncated trapezoid. At the same time pressurized gas is fed to the impact zone. The nozzle serves to blow molten products from the zone of impact of the laser.

As a result of the analysis of the influence of the basic parameters of laser radiation, terms of transfer and focusing, gas-dynamic parameters, absorbance of the surface of implants it was shown that the most important process parameters of radiation are the constant length of the optic path, trajectory parameters of the displacement of the focal point and the offset of the orientation of the axis of focused radiation to the treated surface.

The implementation of the gas-laser technology for the formation of porosity involves the creation of system of coordinate control of the movement of the processed implant and the orientation of the optical head and nozzle relative to the surface.

The increase of the amount of liquid phase can occur under the influence of such factors as the reduction of density of the luminous flux due to the gradual defocusing of the laser beam with the increase of the depth of the hole, the length of exposure, the heterogeneity of the distribution of laser beam intensity across the section due to the mode structure. Therefore, to reduce the amount of liquid phase, it is necessary to optimize the parameters of the laser beam:

- energy-time characteristics of laser radiation, depending on the type of laser, its design;
- spatial characteristics of the laser beam in the place of processing, depending on the characteristics of the optical system of the laser beam machine and the parameters of laser radiation itself.

Laser radiation power must ensure the heating of the surface to the evaporation temperature $T \leq$ 10,000 K. It is possible to determine the required power density for this temperature; if the radius of the cross-section of the beam in the focal plane equals to 100 microns, power density is approximately 0.1-1 kW.

Laser wavelength should lie in the spectral region where the treated material has a higher absorption coefficient.

For titanium it is advisable to use lasers, which generate radiation in the visible spectrum. The wavelength determines the diameter of the light spot in the place of laser beam focusing on the treated surface. The shorter the wavelength of laser radiation and the less angular divergence of a laser beam, the smaller the spot to which it can be focused.

With the decrease of the pulse length of laser radiation the thermal and deformation impact on the treated material outside the radiation zone is reduced. At the short pulse the power density is high. In this case, a small amount of metal may melt and evaporate before the heat from the radiation zone will spread into the surrounding metal.

In practice, in the process of material irradiation, even by ultrashort pulses, around the place of irradiation the so-called heat affected zone is formed, in which the material heats up and melts due to thermal conductivity.

The volume of evaporated material logarithmically depends on the power (energy) density of laser radiation; for longer pulses this dependence is steeper. The pulse length also determines the mechanical stress in the treated material near the impact zone. This means that in order to improve the quality of the treated hole, a laser with very short pulse length should be used.

CONCLUSION

On the basis of the conducted theoretical and experimental research of the laser technology for the creation of biocompatible surfaces of implants and prostheses, the technology of obtaining developed surface of biocompatible implants and prostheses using the method of laser processing of the surface and the laboratory process procedure of laser processing of the surface was developed.

It should be noted that obtaining porous structure on titanium under high pressure of argon makes it possible to obtain a smooth edge of pores with roughness, determined by overlapping of the spots of laser radiation exposure. For finish-machining, pressure up to 15 atm can be applied.

A laboratory process procedure for obtaining developed surface of biocompatible implants and prostheses using the method of laser processing of surface was developed.

ACKNOWLEDGEMENTS

The work was carried out in cooperation with the industrial partner LLC Endocarbon and financially supported by the Ministry of Education and Science of the Russian Federation within the framework of the Grant Agreement No. 14.574.21.0119 of November 26, 2014, the unique identifier for applied scientific research (project): RFMEFI57414X0119.

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