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Experimental Evaluation of the Modes of Laser Processing Of the Surface of Implants and Prostheses.

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ABSTRACT

The paper describes the experimental evaluation of the modes of laser processing of surface with the purpose of the creation of biocompatible surfaces having porous structure. Options for the application of the gas-laser technology for obtaining geometrical dimensions of pores in titanium depending on the diameter of the beam focusing spot are considered, which makes it possible to vary the geometrical dimensions of pores under various conditions of the use of the implant. The paper describes the tests of experimental samples of dental implants, hip and shoulder prostheses, and intervertebral disc prostheses with developed surface on the endosteal part with the purpose of determining the compliance or noncompliance with the preset size of pores of the developed surface.

Keywords: intervertebral disc prosthesis, hip prosthesis, dental implant, shoulder prosthesis, porous structure of an implant, laser processing

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INTRODUCTION

In recent years in the fields of orthopedics, traumatology, dentistry the interest in the development of dental implants, joint and intervertebral disc prostheses with improved biocompatibility and durability has dramatically increased. Another important factor is the acceleration of the processes of osseointegration and the reduction of rehabilitation period.

Numerous scientific studies confirm that most of the technically important materials exhibit instability in biological environments. The oxidation of the material surface takes place. Therefore, titanium, including its alloys, is currently the priority material for surgical use [1,2,3].

So the most important objective is the development of the technology of manufacturing implants and prostheses with a high level of biocompatibility by forming a porous structure of the surface of titanium implants and prostheses using inorganic bioinert coating and recombinant human bone morphogenetic protein-2 (BMP-2) [4,5].

A special part in terms of biocompatibility is played by the allotropic form of carbon (Sp1-hybridization) [6].

In this regard, the new method of the formation of developed surface using laser technology, patented in the Russian Federation [7], is of particular interest.

The use of the new method for the formation of developed surface by means of the laser formation of developed porous surface of titanium alloys, characterized by improved compatibility and integration with living tissues, involves the experimental study of laser processing modes, as well as carrying out tests of experimental implants and prostheses with developed surface on the endosteal part.

EXPERIMENTAL EVALUATION OF LASER PROCESSING MODES

The experiment was carried out using the laser cutting system RX-150 QCW. Samples for cutting were made of titanium WT-6 OST 1 90173. In the course of the experiment the workpiece diameter and the thickness of its walls were changed.

All the experiments, except the first one, were carried out with changing of the maximum laser radiation power and its focusing. The cutting speed and nozzle movement speed were constant. Cutting quality control was implemented using the toolmaker's microscope IMCL 100x50A.

The evaluation of the influence of the reduction of laser radiation power at constant focusing was carried out at the following laser parameters:

Power:	40.39 – 33%
Frequency:	100 Hz
Pulse length:	0.2 ms
Cutting speed:	1.5 mm/s
Movement speed:	5 mm/s

The function of the reduction of laser radiation power was experimentally evaluated at constant focusing on the upper edge of the workpiece wall.

On the basis of the images, obtained from the toolmaker's microscope, it is possible to conclude that the cut line of the laser beam passes goes through the workpiece in a slightly conical shape. Titanium cut line is shown in Figure 1.

Fig.1. Titanium cut line

As can be seen from Figure 1, when the radiation hits the sample, its upper boundary has a narrow and accurate cutoff area. With the increase of depth, the diameter of the beam impact point increases due to the specifics of its geometry. At the same time, under the influence of high temperature all the material inside the cut line is melted out by the action of auxiliary inert argon environment.

In the course of the experiment it was found that with the reduction of the laser beam power within the limits of design values the size and geometry of the melted cutoff area changes insignificantly.

With the increase of the radiation power at the lower edge of the workpiece wall the base of the cone is larger than in case of exposure to lower power.

The influx resulting from the thermal impact on the material distorts the geometrical dimensions and shape of pores. To increase the internal taper angle on the cut line and the volume of the material, which is melted from the inside, it is necessary to increase the laser radiation power.

At the power equal to 100% the experiment was carried out with the uniform offset of the focal distance to the lower edge of the sample wall. The results showed a slight decrease of the vertical distance, along which the pure cut line without influx passes. This change of the cut line is shown in Figures 6 and 7.

In the course of the study of the influence of the focal length the following parameters of laser radiation were used:

Power:	100%
Frequency:	100 Hz
Pulse length:	0.2 ms
Cutting speed:	1.5 mm/s
Movement speed:	5 mm/s

When the focal length is increased, the shape of the cut line on the outer surface of the sample is changed.

The width of the line is increased, and the cut is tapered in the inward direction. This occurs due to the significant area of the focal spot on the surface of the material.

In the course of the study of the influence of the frequency the following parameters of laser radiation were used:

Power:	100%
Frequency:	100, 150, 200, 250 ... 500 Hz
Pulse length:	0.2 ms

Cutting speed: 1 mm/s
Movement speed: 10 mm/s

The experimental studies of the influence of frequency of laser radiation showed that the increase of frequency results in the increase of the cross-sectional area of the cut. The results are shown in Figure 2.

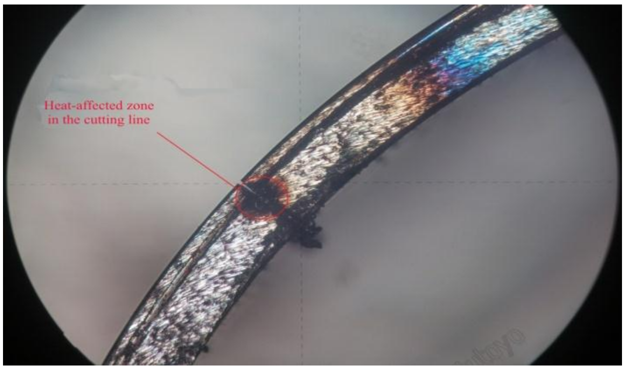

Fig.2. Heat affected zone inside the cut line at a slight increase of the radiation frequency

The increase of the heat affected zone is typical for the increased frequency. The input of heat, exceeding the required level, changes the properties of metal and its structure. The change of titanium color was observed in case of the increase of the radiation frequency. At the values of frequency, close to maximum values, laser impact results in the burning-through of the opposite side of the sample. This effect should be taken into account when forming the pore depth. The increase in frequency results in the increase of the impact depth. Besides, the burning of the material of the sample is observed.

The study of the pulse length was carried out at the following parameters of laser radiation:

Power: 100%
Frequency: 100 Hz
Pulse length: 0.2-0.3-1 ms
Cutting speed: 1.5 mm/s
Movement speed: 10 mm/s

The results of the study showed that the increase of the time of the beam exposure contributes to the formation of geometry inside the cut line.

The conducted studies of laser processing modes showed that one of the main tasks is to obtain the sample with required geometry, with the complete removal of flashes throughout the area of laser radiation exposure. To accomplish this, gas-laser processing using argon was performed [8]. A titanium rod with a square section of 1 mm was used as a sample. Laser cutting was performed with the use of the system of continuous argon jet supply at 4 atm. The resulting sample had the clean edges of the cut line at a given geometry of drawing. The result of processing is shown in Figure 3.

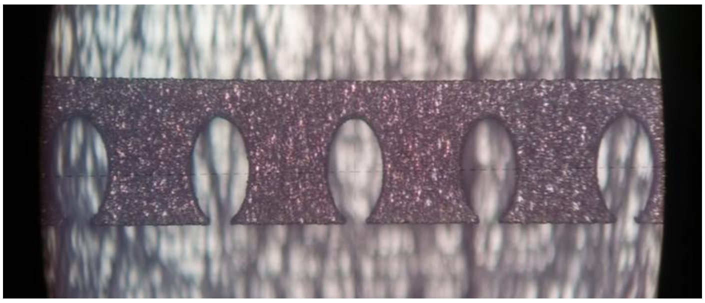

Fig.3. Cutting areas of the titanium rod with the use of the system of continuous argon jet supply at 4 atm

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This mode makes it possible to form the required shape of pores.

Thus, the task of obtaining a finished sample with the required geometry was partially solved by using gas laser cutting.

The conducted experimental studies showed that the critical parameters for the changing of the geometry of the inner area of the cut line are the increased frequency of laser radiation, combined with various length of the pulse affecting the material, and the constant high power of laser exposure. The offset of the focal point didn't result in significant changes; therefore, it is recommended to set the focus point on the outer edge of the sample.

Thus, during the laser processing of holes it is recommended to use lasers with the shorter possible pulse length, and in case of using continuous radiation – to reduce the time of exposure.

In addition to specifying the above-mentioned parameters of laser radiation, when choosing a laser, account should be taken of its performance characteristics and cost. Thus, the choice of a laser for processing holes is a complex task, the solution of which requires taking compromise decisions, when it is required to get high quality of processing, while ensuring high performance and low cost of a laser.

The proposed technology may be used for the formation of the microporosity of the surface of implant components to improve their integration with bone tissue, and of the surface of components of the friction units to improve their anti-friction properties.

Tests of experimental samples of implants and prostheses with developed surface on the endosteal part

The program of testing of experimental samples of implants and prostheses with developed surface on the endosteal part involves the determination of the average value of the pore size, calculation of variance and standard deviation. The average value of pore size shouldn't exceed the rated value (20 μm), and the maximum deviation shouldn't be more than 10.

The toolmaker's microscope IMCL 100x50A was used as a measurement tool for the measurement of pores of the developed surface of the samples of implants and prostheses.

For carrying out tests, the samples of dental implants, hip prostheses, shoulder prostheses, and dynamic intervertebral disc prostheses (6 samples of each type) were manufactured.

A sample of the femoral component of the hip prosthesis is shown in Figure 4.

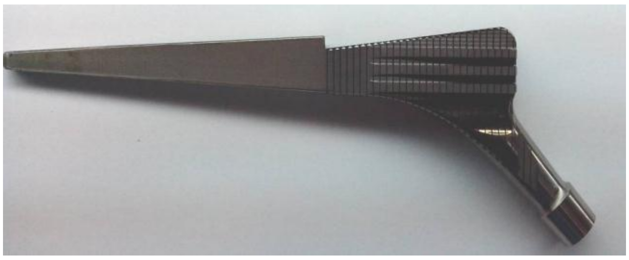

Fig.4. General view of the sample of the femoral component of the hip prosthesis with developed surface

Statistical analysis of the size distribution of the elements of microrelief and micro-porous structure was used as a method of the study of the surface of the implants.

The determinant factors of achieving the maximum strength of the bond between the implant and the bone are the shape and quality of the implant surface [9-10]. The increase of the topography of the implant surface in case of using the gas-laser technology is achieved by its modification by pores.

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The maximum pore diameter, which is to be determined during tests, is shown in Figure 5.

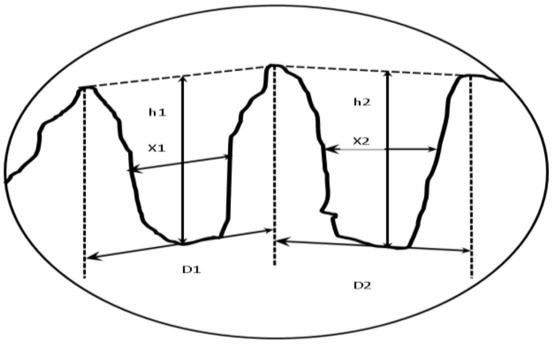

Fig.5. Pore microroughness parameters

Pore diameter (Di) is the distance between two adjacent pore peaks. Pore depth (h) is defined as the distance between an imaginary line, drawn between their highest points of two adjacent peaks, and the bottom of the pore. Peak width (x) is determined at the half of the depth of a pore (h).

According to Figure 5, the maximum pore size diameter corresponds to the diameter of a pore – D1, D2, ... , Di. Therefore, in the process of testing experimental samples of implants and prostheses with developed surface on the endosteal part the values of Di were estimated.

In order to optimize the amount of conducted experimental research and to reduce the cost of conducted research by reducing the number of costly experimental samples of implants and prostheses, tests were conducted for the minimum permissible sample size. Assuming that the distribution of pore diameter corresponds to the normal law, minimum sample size should not be < 30 [9]. This volume was accepted for the study of micropores of each sample.

The results of experimental testing for pore sizes of the samples of implants and prostheses with developed surface on the endosteal part are presented in Table 1.

TABLE.1.Statistical data on the sizes of the pores, obtained in the process of gas-laser processing of the surface in dental implants, total hip prosthesis, shoulder prosthesis, dynamic intervertebral disc prosthesis

Parameter	Unit	Article numbers			Require-ments to the para-meter		Parameter statistics		
		Technical specification	Testing program	Testing procedure	Rated value	Maximum deviation	Average value	Standard deviation	Variance
Size of micropores in dental implants	µm	4.2.1	4.1	6.1	20	10	15.6	5.1	26.1
Size of micropores in the total hip prosthesis	µm	4.2.1	4.1	6.1	20	10	17.1	3.2	11.2
Size of micropores in the shoulder prosthesis	µm	4.2.1	4.1	6.1	20	10	17.5	3.8	14.5
Size of micropores in the dynamic intervertebral disc prosthesis	µm	4.2.1	4.1	6.1	20	10	18.3	3.9	15.3

CONCLUSION

The experimental evaluation of the modes of laser processing was carried out. The geometrical dimensions of pores in titanium in case of using the gas-laser technology are determined by the diameter of the beam focusing spot. It makes it possible to vary the geometrical dimensions of pores depending on the conditions of the use of the implant. The increase of the laser beam displacement speed results in the increase of the instability of pore geometry. The increase of the pulse length results in the increase of pore sizes. The study of the minimum limit negative angles of the formed pores showed that the burn-through of the upper edge of pores doesn't occur at angles above 25°. The gas-laser technology makes it possible to ensure the formation of high-quality structure and shape of a porous surface.

The tests of experimental samples of dental implants, hip and shoulder prostheses, and intervertebral disc prostheses with developed surface on the endosteal part with the purpose of determining the compliance or noncompliance with the preset size of pores of the developed surface were carried out. The method of testing the samples of implants and prostheses is based on the evaluation of the elements of the microrelief of the porous structure according to their size. The estimated parameter is the pore diameter, that is, the distance between two adjacent peaks.

The tests were conducted for four types of the samples of implants and prostheses with developed surface, for six samples of each type, wherein each sample had 30 pores. A test item is considered to have passed the test, if the average pore size does not exceed the value of 20 µm. The results of the tests of the samples of implants and prostheses are characterized by average values, not exceeding the value of 20 µm, determined in the technical specification.

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