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NANOCOMPOSITE BASED ON SiC/Si: A NEW BIOMORPHIC MATERIAL FOR MAXILLOFACIAL SURGERY (EXPERIMENTAL STUDIES)

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The aim of the study was to investigate the interaction of experiment samples biomorphic ceramics based on silicon carbide with bone tissue by scanning electron microscopy. To achieve this goal in a laboratory experiment 20 rats underwent implantation of test material samples in the lower jaw bone tissue. Animals were removed from the experiment in terms of 7, 30 and 90 days after the start of the experiment and the subsequent investigation of the material surface and area of it contact with the bone tissue.

Based on these results, it was found that the investigated ceramic microarchitectonics promote the process of reparative osteogenesis by providing conditions for colonization of living cells on the surface of the material. It was proved the possible to contact the coexistence of bone and implants of biomorphic silicon carbide with no signs of rejection or its delimitation. Analyzing results of SEM revealed bone adaptation and bone restructuring in the presence of silicon carbide and its germination pores close fit to the material to its surface.

Introduction

Research and introduction into clinical practice a new class of implants materials which were created in accordance with the principles of biomimetics, as a very promising area of medical materials science nowadays. These materials were synthesized from biological tissues or have properties similar to living structures [1, 2]. As an example, plant material, including wood and its derivatives, has a complex structure and is characterized by a great mechanical resistance, low density, high toughness, elasticity and endurance against any damage. These advantages are caused by genetically formed structure that had developed and perfected in the process of evolution [3, 4].

In this aspect, functional similarity of wood and bone is noteworthy, in particular their ability to remodeling of the internal structure in response to external, often mechanical irritation, the presence of cambial cell layer for peripheral volume increase and continuous self-renewal. The wood as a matrix for the manufacture of carbon materials with natural architectonics increasingly attract the attention of researchers from different countries [5, 6]. Therefore, based on these natural materials more and more types of ceramic materials have been produced.

Production of ceramics with biomorphic properties in most cases involves two main stages: creation of carbon matrix from biological preform and its direct conversion into ceramics. The presence of carbon matrix of a biological object allows obtaining material which is pseudomorphic to this object and it will have similar structure to the biological sample at the micro, meso and macro levels. Such natural hierarchical porous structures have a high level of complexity that is not available in other modern technologies of production [7].

Potentially promising material of this class has been developed at V. Lashkarev Institute of Semiconductor Physics, NAS of Ukraine. It has been made by silica impregnation of "channel" carbon matrices that have been obtained due to pyrolysis (carbonization) of different species of wood [8].

At the same time one of the pressing issues of modern reconstructing surgery is the search and development of new implant materials to expand the range of treatment methods while eliminating defects, deformities of tissues or impart them a new shape and function. Conducting a series of reconstructive operations requires the use of synthetic materials as fixators of bone fragments, barriers between different types of tissue, supports to hold the shape or the implementation of a specific function.

Taking into account the prospects of ceramics based on silicon carbide as a material for implantation for solving various problems of reconstructive surgery, we set the goal to research experimentally the reaction of bone tissue and peculiarities of reparative osteogenesis in the implantation area of samples of ceramics based on silicon carbide by scanning electron microscopy (SEM).

Materials and methods

To achieve this goal we performed an experiment on 20 white laboratory male rats, weight -250-280 g. Foraminous bone defects of the mandible were applied with bur (diameter - 1,5 mm, depth -3 mm) under intramuscular ketamine narcosis according to the principles of medical ethics. After hemostasis silicon carbide samples of the same size with a diameter of 1,5 mm and a length of 2 mm were placed into the defects. The tissue layers were cut down. Five intact rats served as a control group. The animals were kept under normal conditions of vivarium and they were taken out of the experiment in terms of 7, 30, 90 days after implantation by lethal dose of the drug for narcosis.

SEM research of the contact zone of samples of biomorphic ceramics based on silicon carbide with bone tissue after removing them from the body of experimental animals were carried out on the device JEOL-100 (Japan) in Institute of Physics, NAS of Ukraine. After intake of the specimens defatting and washing of bone fragments in 96% alcohol, after they were dried out in a vacuum. In order to prevent the accumulation of surface charge on the surface of the sample, which could potentially affect the secondary electron emission, it was covered with a thin film of gold with thickness of 100 A˚ by cathode sputtering. The thickness of the film deposition was tested by piezoelectric crystal sensors directly inside the vacuum evaporator. Scanning electron microscopy was carried out in the various fields of view, with an increase from 1:40 to 1:10,000, researching the entire surface of the sample of biomorphic ceramics and adjacent areas of the surface layers of the bone in the area of contact with the bio SiC.

Results and discussion

The study of biomorphic silicon carbide surface by SEM revealed the presence of cellular structure of given material, it was found that the diameter of the pores ranged from 10 to 100 microns, and a microscopic picture of the bio SiC surface was very similar to the SEM image of the sample surface of bone tissue, confirming biomorphic researched ceramics based on silicon carbide (Fig. 1).

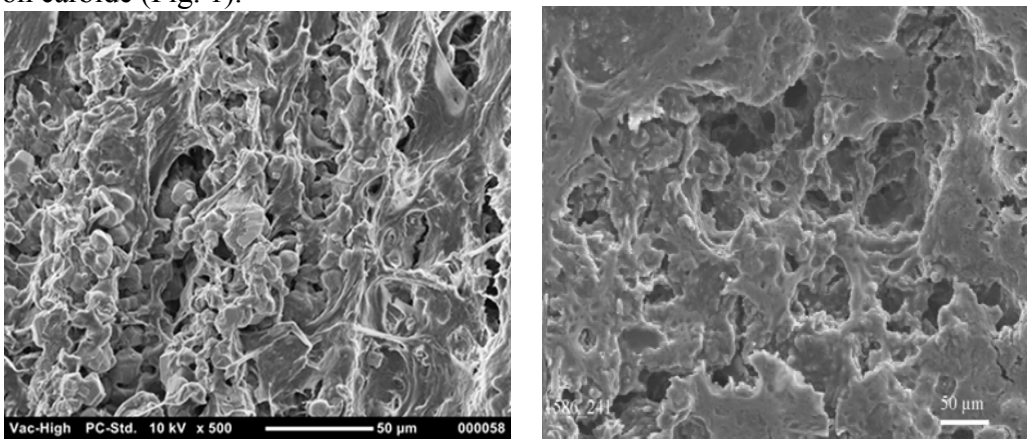

Fig. 1. SEM images of the sample surface morphology of biomorphic silicon carbide and bone tissue.

In conducting scanning electron microscopy 5 samples of biomorphic silicon carbide removed from the body of experimental animals in a week after, implantation revealed settlement of pores of given material by living cells (Fig. 2). In all cases there was predominant colonization of the pores of given material by the cells in the form of clusters that resemble the formation of colonies. Their predominant location observed in the region of pores in the structure of biomorphic ceramics.

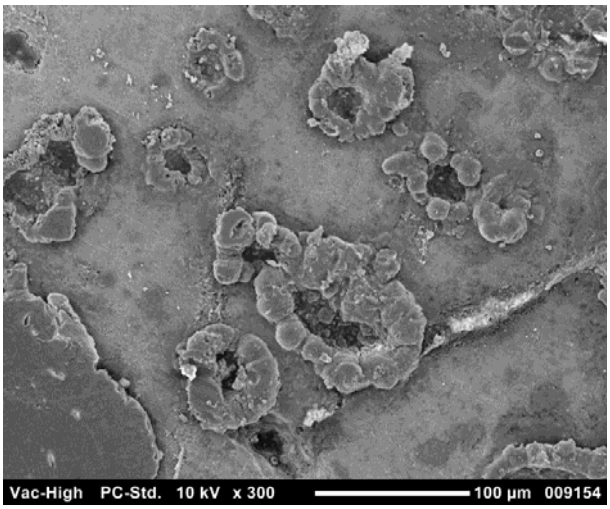

Fig. 2. SEM images of surface of silicon carbide samples within 7 days after implantation.

This fact can be interpreted as the potential possibility of the material to promote the process of reparative osteogenesis due to the presence of conditions for cells adhesion. The main reason for this phenomenon we see in the peculiarities of architectonics of the researched material revealing in some of its structural similarity to bone tissue.

In the analysis of SEM images of silicon carbide surface in bone tissue obtained one month after, enthesis of the implants into the body of experimental tissues revealed that in all observations material surface completely covered with a continuous layer of living cells without a clear organization. With greater magnification it was found that this coating consists of many layers of cells intimately soldered together by intercellular matrix. (Fig. 3).

The presence of direct contact of living cells with the structure of researched material, their proliferation with deposition of intercellular matrix on its surface indicates favorable conditions for integration of the material in the structure of bone tissue. In presented SEM images, the transition from the colonial character of proliferation of living cells in initial phase of regeneration to formation of a continuous coating layer on the surface of the material is marked indicating the conditions for cell regeneration.

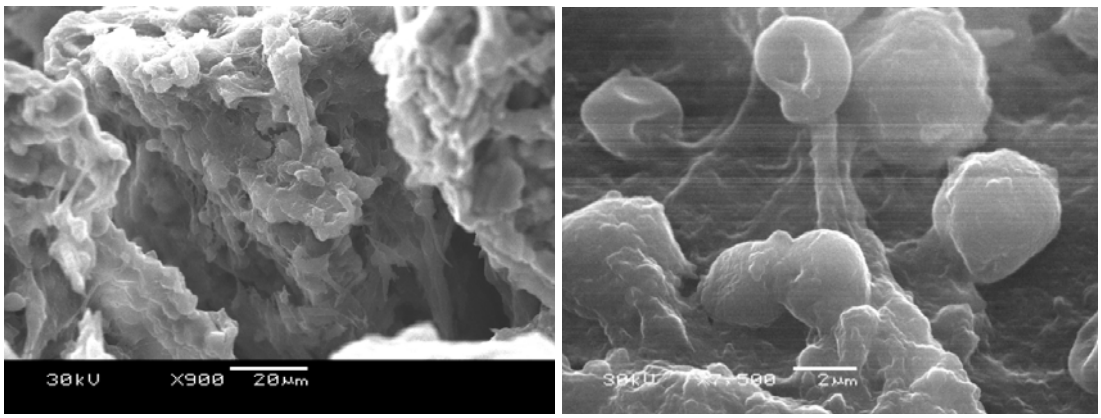

Fig. 3. SEM images of the surface of the implant from biomorphic silicon carbide after a month from the start of the experiment.

In the analysis of SEM images of contact area of biomorphic silicon carbide with bone tissue at low magnification a craterform surface reconstruction of the adjacent bone tissue toward the surface of the implanted material is clearly visible. This fact can be explained by the fact that during the experiment the bone defect was formed with bur and introduced material was not adapted to its shape. However, in the SEM images in 90 days after surgery there was elimination of the consequences of the destruction of bone tissue, ending of its reconstruction and adaptation to the surface of implanted fragment of biomorphic silicon carbide (Fig.4). This indicates the possibility of normal flow of the processes of reparative regeneration of bone tissue in the presence of biomorphic silicon carbide and the possibility of bone tissue to adapt to the peculiarities of relief of the implanted material surface. This position confirms the high biocompatibility of the researched biomorphic ceramics and the absence of negative impact on the course of reparative regeneration of bone tissue.

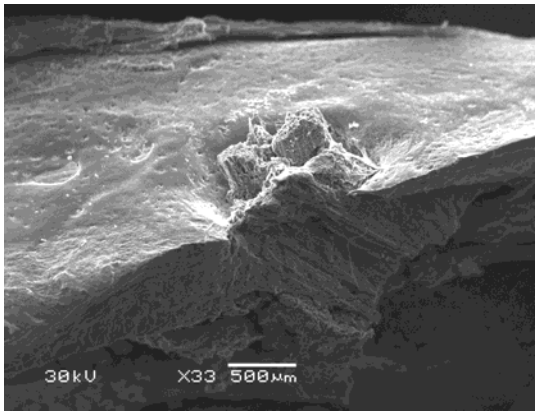

Fig. 4. SEM of the surface experimental bio-SiC sample in the area of its contact with bone tissue.

In the microsection “material-bone tissue” in the plane perpendicular to the surface of the mandible of experimental animals, was observed a tight attachment of bone tissue to the material. Thus in many places narrow fissure of the contact is interrupted or is unclear due to bone ingrowth into the pores of biomorphic ceramics. Especially narrow fissure or its visual absence is observed in the area of the contact of the material with cortical bone. In many places, there is invagination of bone tissue with its ingrowth into the pores of researched material (Fig. 5). This picture gives reason to claim the possibility of reconstruction of bone tissue bordering with silicon carbide and its adaptation to the surface of the material with the ingrowth of bone trabecula into the pores of the material.

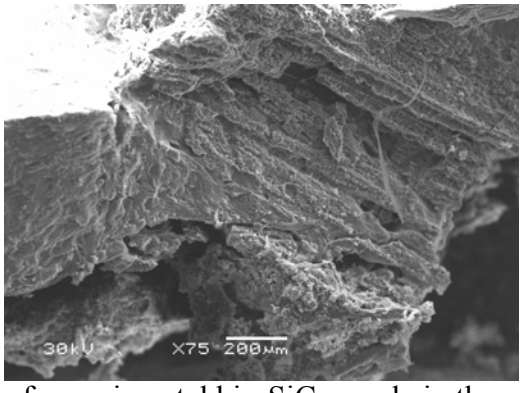

Fig. 5. SEM of the surface of experimental bio-SiC sample in the area of its contact with bone tissue.

Thus, the above mentioned results confirm the prospects of biomorphic ceramics based on silicon carbide as a material for the manufacture of implants for various purposes for use in maxilla-facial surgery.

Obtained data deny the possibility of negative impact of implants of silicon carbide on the course of reparative regeneration of bone tissue. According to the results the existing microarchitectonics of given ecoceramics that resembles the structure of bone tissue, promotes the flow of reparative osteogenesis processes by providing conditions for colonization of the surface of the material by living cells.

The possibility of contact coexistence of bone tissue and implants with biomorphic silicon carbide without signs of its rejection or its delimitation is the main background for conducting clinical researches regarding the use of the implants made from this material with the purpose of elimination of defects and deformities of the maxilla-facial area. As the basis for this, we consider the results of SEM of the contact area of biomorphic silicon carbide with bone tissue including revealed facts of adaptation and structure reconstruction of the bone tissue in the presence of silicon carbide and its ingrowth into the pores of the material and a tight attachment to its surface. Taking into consideration the mechanical properties of silicon carbide and its potential possibility of implants manufacture of any shape and size of the readily available sources of raw materials this branch of scientific research in dentistry seems to be promising.

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НАНОКОМПОЗИТ НА ОСНОВЕ SiC / Si: НОВЫЙ БИОМОРФНЫЙ МАТЕРИАЛ ДЛЯ ЧЕЛЮСТНО-ЛИЦЕВОЙ ХИРУРГИИ (ЭКСПЕРИМЕНТАЛЬНАЯ ИССЛЕДОВАНИЯ)

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Целью исследования было изучить взаимодействие экспериментальных образцов биоморфной керамики на основе карбида кремния с костной тканью с помощью сканирующего электронного микроскопа. Для достижения этой цели лабораторным животным (20 крыс) проводили имплантацию образцов исследуемого материала в нижней челюсти костной ткани. Животные выводились из эксперимента через 7, 30 и 90 дней после начала эксперимента с последующим исследованием поверхности материала и площади его контакта с костной тканью.

На основании этих результатов было установлено, что микроархитектоника исследуемой керамики содействует процессу репаративного остеогенеза, обеспечивая условия для колонизации живых клеток на поверхности материала. Это подтверждается возможностью контактного сосуществования кости и имплантатов биоморфного карбида кремния без признаков отторжения или его делимитации. Анализ результатов СЭМ показал, что имеет место адаптация костной ткани и реструктуризация кости в присутствии карбида кремния, прорастание ткани в поры и плотное прилегание к поверхности материала.

НАНОКОМПОЗИТ НА ОСНОВІ SiC / Si: НОВИЙ БІОМОРФНИЙ МАТЕРІАЛ ДЛЯ ЩЕЛЕПНО-ЛИЦЕВОЇ ХІРУРГІЇ (ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ)

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Метою дослідження було вивчення взаємодії експериментальних зразків біоморфної кераміки на основі карбіду кремнію з кістковою тканиною за даними скануючої електронної мікроскопії. Для досягнення цієї мети лабораторним тваринам (20 щурів) здійснили імплантацію зразків досліджуваного матеріалу в нижній щелепі кісткової тканини. Тварини були видалені з експерименту на 7, 30 і 90 день після початку експерименту з подальшим дослідженням поверхні матеріалу і площі його контакту з кістковою тканиною.

На підставі цих результатів було встановлено, що мікроархітектоніка дослідженої кераміки сприяє процесу репаративного остеогенезу, забезпечуючи умови для колонізації живих клітин на поверхні матеріалу. Це підтверджує можливість зв'язуючого співіснування кістки та імплантатів біоморфного карбіду кремнію без ознак відторгнення або його делімітації. Аналіз результатів СЕМ показав, що має місце адаптація кісткової тканини і реструктуризація кістки в присутності карбіду кремнію, проростання тканини в пори та щільне прилягання до поверхні матеріалу.