

Investigation of Osseointegration of Porous Materials for Orthopedic Implants

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BIOGRAPHICAL NOTES

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KEY WORDS

Porous Materials, Orthopedic Implants, Implants

ABSTRACT

The paper presents research regarding osteointegration of porous materials for implants made for Co-Cr-Mo and titanium with Bioglass type-S2. All the materials were prepared using cold pressing and sintering. The research was made on the castrated goats av-

eraging one year of age, from this oneself herds. Bone growth process on surfaces of implants made with additional bioglass was significantly intense. The amount of osseous tissue and the number of connection points are significantly increased. On surfaces of titanium implants few areas of stochastic callus formation were observed. In that case areas of preferential bone integration have uneven surface due to technological process. A significant difference appears in osseous tissue growth morphology on implant surface. In porous implants bone grows around the pores of an implant. The obtained results showed that porosity influences callus growth intensity beneficially on the implant structure. Use of bioglass increases bone growth intensity on implant surface.

INTRODUCTION

Due to their superior mechanical properties and high corrosion resistance, pure titanium, titanium alloys and Co-Cr-Mo steel have been widely used in the manufacturing of dental and orthopedic implants. However the bioactivity of their surfaces is not high enough to induce the growth and fixation of the bone tissue [12, 13]. Consequently, in order to improve bone regeneration, some procedures of titanium surface modification are being intensively conducted. Also, increasing demands of modern biomaterials medicine induce development of new technological solutions that allow obtaining materials possessing advanced bioactive properties [1, 10, 26].

An ideal biomaterial for medical applications is expected to exhibit excellent biocompatibility with no adverse cytotoxicity, excellent corrosion resistance, and a good combination of mechanical properties such as high strength and fatigue resistance, low modulus, and good wear resistance [12]. As a result, intensive research is being carried out in order to obtain materials with properties comparable to replaced tissues. One of the prospective directions of research is the use of porous metallic materials to stimulate the osseointegration process. The application of materials with appropriate porosity allows obtaining mechanical fixation of the implant without bone cement due to bone growth into its porous structure [8, 10, 19, 26, 24]. Modern technologies, for instance, powder metallurgy offer new possibilities of obtaining original porous alloys and composite materials. Pure titanium and titanium al-

loys are now the most promising alloys for biomedical applications and are the most commonly used implant materials. Thus over the past several years beta titanium alloys deprived of aluminum (Al) and vanadium (V) have become materials of increasing importance for biomedical applications [2, 8, 9, 18, 19, 21].

Successful replacement of most damaged organs and tissues comprising the human body with synthetic organs and various replacement elements is often the sole method of life and health-preservation in humans. Osteosynthesis of bone implants and the effect thereof on a living organism are not yet fully explored.

After a thorough analysis of available reports from relevant literature it can be observed that implantation reaction-related issues are not unequivocally explained. For this reason, this essay's aim is to help better explain and understand these issues.

The integration of an implant into the osseous tissue is a complex process which has not yet been fully explored. It is a process largely dependent both on a number of graft-related factors, as well as on the condition of the patient. On the side of the implant, the main affecting factors include: chemical constitution, material homogeneity, implant surface quality; composition, type and thickness of protective layers (bioglass, hydroxyapatite, etc.) size and shape of the implant, the process of implantation and adjustment of the implant to accommodate natural anatomy. The main organism-related factors include: osseous tissue quality, any possible pathogenic processes such as osteoporosis, application of bone cement and/or curatives during surgery, allergic sensitivity to metallic implants, patient's age, physical condition, environment (air and food pollution, etc.).

Careful study of integration mechanisms allows to understand the cause and method by which osteocytes factor into osteointegration. The authors of this essay [13, 20, 25] have concluded that selecting an appropriate method of implant integration into the osseous tissue plays a major role in healing of implants.

Implant surface becomes a site for rapid active osteogen growth and replication. Some of these cells differentiate into osteoblasts [14]. Morphological identification of osteogenic tissue is difficult and mostly limited to confirming its presence, by contrast, in the vicinity of already differentiated osteo-

blasts [4].

In the presence of a stimulus, such as irritation or discontinuity of tissue (by fracture or insertion of an implant), osteogenic tissue becomes activated. Active osteogenic cells display a different morphology from static cells. [5, 14]

Osteogenic cells present in the vicinity of vessels differentiate into osteoblasts, while the cells occurring far from blood vessels - into chondroblasts. The process of differentiation of osteogenic cells is highly complex and can be affected by various physical and chemical microenvironmental factors (pressure, mechanical forces, growth stimulation agents, etc.) which cannot all be determined at this time [22, 25]. The integration and healing of implants is also affected by outer surface coarseness. The higher the coarseness level - or the more porous the coating material after the likeness of bone - the stronger the implant-bone connection [1, 23].

MATERIALS AND RESEARCH METHODS

Selection of materials

This research was conducted using porous sinters obtained from powder Co-Cr-Mo alloy and titanium. The preparation of said materials included selecting both pure alloy and one with a ceramic additive of CaO-P2O5-SiO2 bioglass [15, 16].

Grafts have been made observing the following condition variants:

- *pure sintered Co-Cr-Mo,*
- *sintered Co-Cr-Mo with 10% CaO-P2O5-SiO2 additive,*
- *solid titanium,*
- *titanium with 5% CaO-P2O5-SiO2 additive,*
- *titanium with 10% CaO-P2O5-SiO2 additive.*

The implants were cylinder-shaped, 7mm in diameter and 7mm in height. So prepared implants were grafted into the epiphysis of goats from a single flock. The animals used were of both sexes - somatically mature hens (4 subjects) and neutered males (5 subjects). The research on animals was conducted at SGGW Warsaw with the permission of the Third Local Ethics Committee, permission No. 19/2002.

Research methods

The first stage of the experiment comprised the preparation of animal subjects. The animals were put under general anesthesia and holes - 7mm in diameter and 8mm deep - were drilled in the revealed bone surface. A spare millimeter was left in reserve for the periosteum.

Subject observation was terminated after six months. The procedure was followed by further study of the implants and the surrounding osseous tissue.

Simultaneously, microscopic observation was conducted of the surface points of contact of the implant with osseous tissue. The tool used was a scanning electron microscope HITACHI S-3000N equipped with a freezing table. Employing the freezing table allowed for conducting observation of damp bone samples without the need for special preparation thereof (drying and steaming). The observation was conducted in secondary emission (SE) and speeding voltage of 15kV.

In the next stage, areas of contact and clearance between osseous tissue and implants were defined. Computer image analysis was used in the evaluation thereof. The flank area of contact between the implant and osseous tissue was defined with a method known as the dissector method with 1mm step. The diagram representation of this method is presented in Fig. 1.

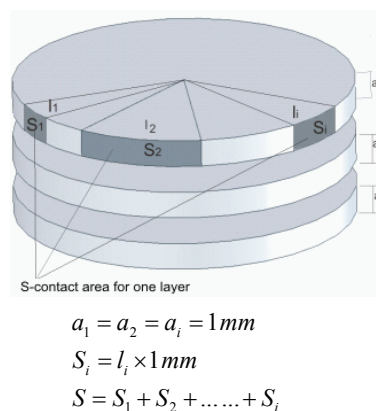


Fig. 1 Diagram representing the evaluation method for contact area between implant and tissue

Sections obtained with this method were then registered with Canon EOS 5D. A sample picture has been presented in (Fig. 2a). Each image has been put through edge detection filter (Fig. 2b). Next, a circle of implant-sized perimeter was inscribed into the resulting outline (Fig. 2c).

The above operations allowed for precise identification of the contact area between the implant and the surrounding tissue (Fig. 2d). The difference in areas between the outline and the inscribed circle constitutes the amount of clearance gap between

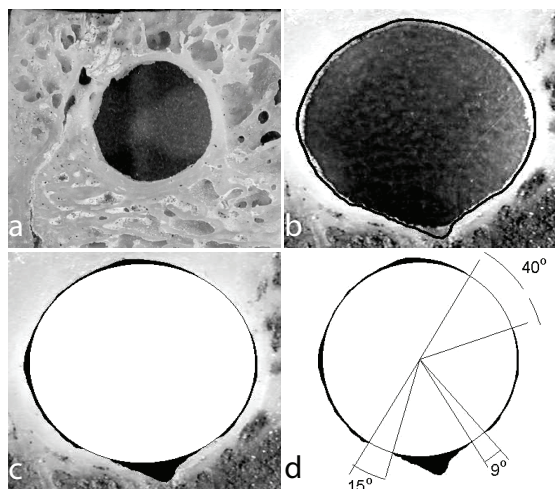


Fig. 2 A sample image of the analyzed osseous tissue layer: a) sample picture, b) with the hole edge marked, c) with the inscribed implant, d) contact area between implant and tissue

the implant and the tissue. To define the superficies of the clearance area, the computer image analysis software was used.

RESULTS

The macroscopic testing showed that the weakest osteointegration was achieved in the case of solid alloys. All implants were loosely embedded and easily removed from the bone after post-processing. Simultaneously conducted microscopic testing of the implant surface also confirmed a lack of clearly defined places of bone adherence to the implant surface (Fig. 3). In the case of bone, a smooth surface is observed, with no distinctive elements that might have maintained a connection with the implant (Fig. 4). It provides evidence that a reconstructing bone found no ground for ingrowth and, consequently, embraced tightly the graft without producing osseous bridges.

In the case of porous titanium implant with bioglass additive an improvement in osteointegration with surrounding osseous tissue was observed. The most promising results were achieved with 5% bioglass additive (Fig. 5). Here we have a number of areas with visible signs of implant-tissue ingrowth, as well as clear areas with no traces of connective tissue.

Figure 6 shows a fairly smooth surface with ragged spots which indicates the presence of new tissue, irritated while removing the implant. This fact leads to the conclusion that there exists a connection be-

tween the graft and osseous tissue which has found suitable site where to anchor into the implant surface. The results from image analysis confirm this conclusion.

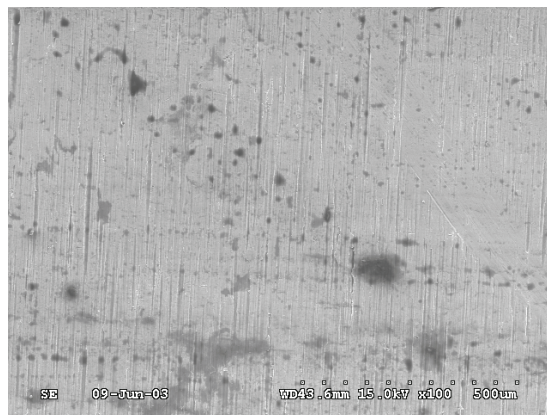


Fig. 3 Titanium alloy implant surface, mag. x100

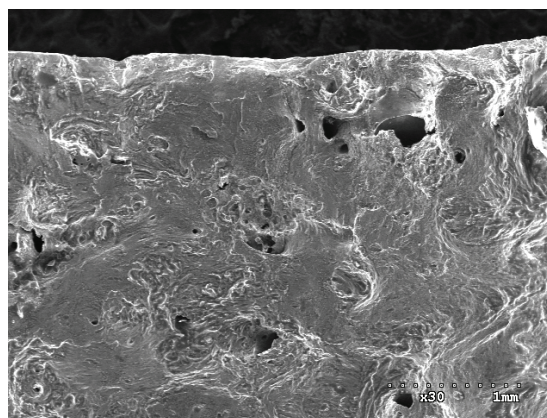


Fig. 4 Bone surface at the point of contact with titanium implant, mag. x30

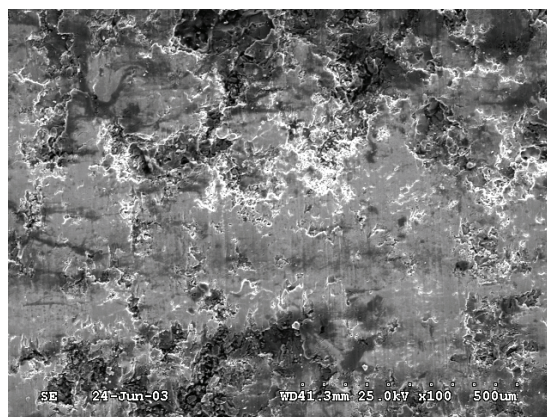


Fig. 5 Surface of porous titanium with 5 % bioglass implant (mag. x100)

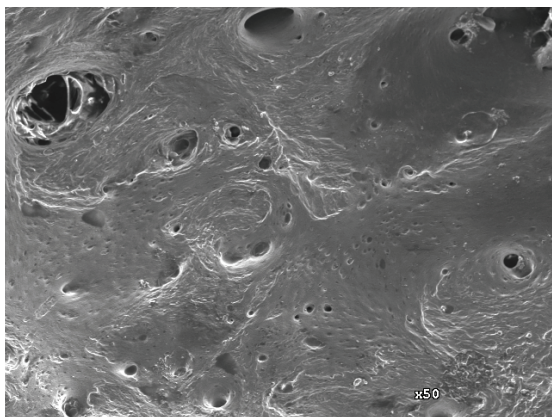


Fig. 6 Connection area of bone and porous titanium with 5% bioglass additive implant, mag. x50

In the case of an implant with 10% bioglass additive, broken osseous bridges have been observed. This confirms the existence of a connection between bone and graft. High porosity of the osseous tissue has limited the number of those connections and prevented the formation of a solid adhesion. The results of an analysis of contact area between implant and tissue confirm this.

To sum up the research results for titanium implants it can be said that implants made with the bioglass additive display the least looseness from the bone. The largest loose areas remained with the titanium implants. The best integration was observed in implants with 5% bioglass additive, while the worst - with solid titanium implants.

In the case of implants created from pure sintered Co-Cr-Mo, no clear signs of connection with the surrounding tissue were observed. However, microscopic evaluation of the implant surface has revealed sparse clusters of connective tissue (Fig. 7). This can be interpreted as an attempt at ingrowth of the forming bone (Fig. 8).

The structure of tissue surrounding an implant presented in Fig. 10 indicates the places of direct connection with the implant. Here we observe a smooth surface with marginal signs of severed connective tissue.

Initial evaluation of sintered Co-Cr-Mo with 10% bioglass additive indicates a better adhesion of the implant to the bone. Microscopic testing confirmed the presence of numerous areas of ingrowth (Fig. 9). The structure of bone surface in direct contact with the implant is presented in (Fig. 10).

An uneven yet fairly smooth surface was observed,



Fig. 7 Surface of sintered Co-Cr-Mo, mag. x100

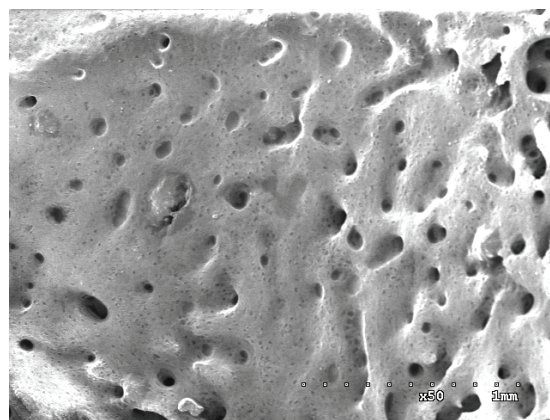


Fig. 8 Connection area of bone and sintered Co-Cr-Mo implant, mag. x50

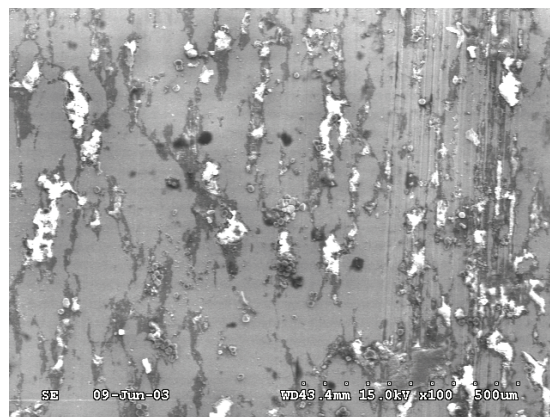


Fig. 9 Surface of sintered Co-Cr-Mo with 10% bioglass, mag. x100

with marginal traces of connective tissue, indicating a connection between bone and sintered Co-Cr-Mo with 10% bioglass additive. Additionally, a large tis-

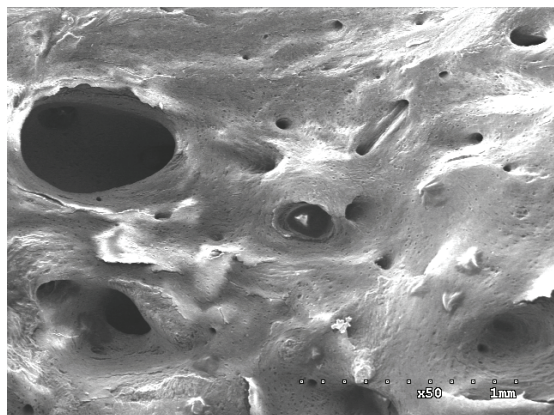


Fig. 10 Connection area of bone and sintered Co-Cr-Mo implant with 10% bioglass additive, mag. x50

sue defect was observed (which for the most part is a pore of the cancellous structure of the bone tissue) and had a significant influence on the loose area test results.

We can conclude that the largest connection area is found in titanium implants with 5% bioglass additive. The connection created by samples of solid titanium was marginal and oscillated around 0,3mm², while for the sample containing 10% bioglass additive it was approximately 0,9mm². Both types of sintered Co-Cr-Mo displayed similar measurement values of connection areas (approximately 1mm²). The record sheet for connection area measurement results is shown in Fig. 11.

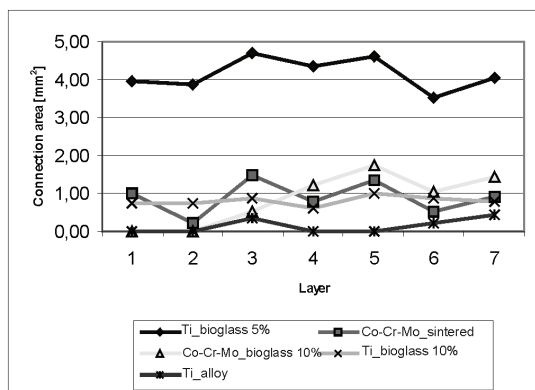


Fig. 11 Implant-tissue connection area measurement results

An analysis of the abovementioned results leads to the conclusion that the method of grafting implants in the bone significantly affects the conditions of implant integration and healing. Embedding the

implant in an bone indicates differences in implementation-related reaction mechanisms regardless of the type of implants used. In all tested samples the distribution of loose areas was irregular and indicates possible mutual ingrowth of bone and implant. The sample of 3D visualization of contact area for Ti with 5% bioglass is presented in Fig. 12.

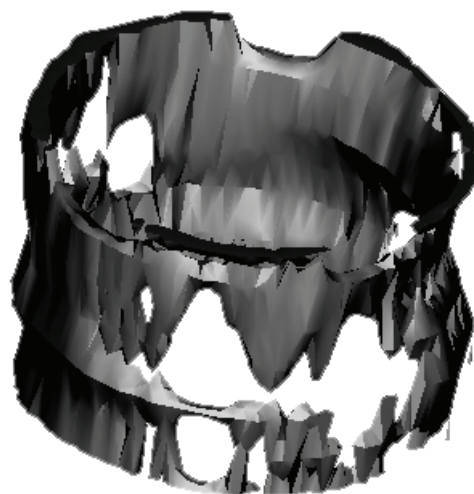


Fig. 12 Sample of 3D Vizualization of contact area for Ti with 5% bioglass

SUMMARY AND CONCLUSIONS

The practical part of this work comprised a series of experiments, conducted with the aim to compare tissue adaptation processes for titanium and Co-Cr-Mo implants produced using powder metallurgy with active CaO-P2O5-SiO2 bioglass additive.

The results obtained in the process confirm that larger connection areas are found in implants enhanced with the bioglass additive. The most promising results were achieved for the titanium implant with 5% bioglass additive and the Co-Cr-Mo implant with 10% bioglass additive.

If the implant is loosely embedded in the implant bed, in the process of integration and healing around it (in the clear space) fibrous connective tissue growth can be observed. This situation occurs when there was a lack of strong connection between the bone and the implant in question. Good results were observed in places where the implants were pressed into previously prepared holes. The connection between osseous tissue and implant was initiated and maintained from the beginning.

This resulted in the implants carrying over the tension originating in the osseous tissue. This, in turn, stimulated the growth of new osseous tissue, and of strong bonds. [18, 19, 20]

The research conducted leads to the following conclusions:

■ *solid titanium implants display the weakest degree of osteointegration with osseous tissue, while sintered titanium with 5% bioglass additive proved to be the most effective,*

■ *introducing bioglass into sinters, as well as altering its amount, significantly affects the conditions of implant integration and healing and, concurrently, points to the existence of a variety of implementation-related reaction mechanisms,*

■ *introducing bioglass facilitates the reconstruction of osseous tissue around an implant.*

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