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Corrosion resistance of metallic implants used in bone surgery

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ABSTRACT

Purpose: The purpose of the research was analysis of influence of mechanical damages on the implants' surface made of Cr-Ni-Mo steel on the pitting corrosion resistance. Analysis was performed for implants after different time of implantation applied for stabilization of the funnel chest and for stabilization bone fractures, as well as for intramedullary nails in the initial state.

Design/methodology/approach: Research were performed on three groups of implants after different implantation time. Research were based on the potentiodinamic tests by recording the anodic polarization curves. The tests were performed in the Tyrode's physiological solution.

Findings: The research effect was determination the corrosion potential E_{corr} and breakdown potential E_b for three groups of implants after different time of implantation and different mechanical surface damages. On the basis of investigation it was stated that for all implants the breakdown potential was in the range of E_b = +549 – +1017 mV and the corrosion potential was in the range of E_{corr} = -143 – +103 mV.

Research limitations/implications: The obtained results can be applied to comparing the effects of possible postoperative complications. They also show the relation between the damage of surface layers and implantation time. The values of corrosion and breakdown potentials indicate good corrosion resistance of the applied austenitic stainless steel.

Practical implications: The essential influence on the corrosion resistance had the time of implantation and size of surface damages. The results of research of implants made of Cr-Ni-Mo austenitic stainless steel presents that the steel was performed quality requirements for metallic biomaterials used for tested implants.

Originality/value: The work presents the results of pitting corrosion tests for metallic implants made of Cr-Ni-Mo steel in the initial state and after different implantation time.

Keywords: Biomaterials; Pitting corrosion; Biocompatibility; Corrosion resistance

MATERIALS

1. Introduction

Significant progress in development of materials used in medicine, in particular metallic biomaterials used in bone surgery, causes the need of continuous control of their quality in clinical conditions.

In order to fulfill their fundamental task – stabilization of fracture, they should be characterized by appropriate mechanical properties and biocompatibility. It means they should not initiate severe or chronic reactions, inflammatory, toxic or allergic reactions or should not cause irritation of surrounding tissues [1,2].

Austenitic stainless steel (Cr-Ni-Mo) is a first metallic biomaterial which was adapted to be implanted in human body. The chemical composition ensures paramagnetic, austenitic structure [1,3]. Carbon concentration was limited to the value of 0.03% to ensure austenite stability, good corrosion resistance and biocompatibility [1-3,5-19].

Corrosion resistance of metals and their alloys in body fluids influences biocompatibility and is a factor determining their usefulness to be applied in medicine as implants. Metallic biomaterial implanted to human body contacts body fluids which can be recognized as electrolytes. After implantation neutral pH is changing. Depending on the implantation time and correctness of the healing process the pH value is in the range 6.8 – 7.4. Corrosion issues of metallic biomaterials focus on corrosion of biomaterial itself and corrosion resistance of determined forms of implants in human body fluids [1,2].

Pitting corrosion leads to the creation of pits as a result of anodic reaction initiated by activating ions and cathodic reaction in the presence of oxidizing factors. Initiation of pitting corrosion is conditioned by the existence of breakdown potential. The creation of pit is initiated by adsorption of activating, aggressive ions in less resistant areas of oxide layer [1,2,6-19].

Corrosion resistance of the steel is the result of its susceptibility to create adhesive, passive layers. Passivity appears when metal or alloy does not react with environment, due to inhibition of anodic process [1,2]. Passive layer can be destroyed by mechanical damage on implants' surface. The damage can be caused by prebending.

2. Material and methods

Based on implantation time and mechanical surface damages of implants during implantation and their corrosion resistance, the implants for tests were divided for three groups. The first group contained the intramedullary nails which were implanted in the body for 9 weeks, the second group represented implants applied for stabilization of the funnel chest and for stabilization of bone fractures after 6 – 36 months. For comparison the research of samples from intramedullary nails in the initial state has been performed – third group. Places of the largest mechanical surface damages and places of the smallest damages as the comparison were observed and tested. 16 samples of metallic implants for research were used.

Implants made of Cr-Ni-Mo austenitic stainless steel were electrochemically polished and passivated to obtain the higher pitting corrosion resistance – Fig. 1.

On the first the macroscopic observations of surface damages after different implantation time were performed with using MST ZOOM PZO microscope. It allows to define type and amount of damages which were result of the preparation before implantation, especially during the prebending and during their removing from the body – Fig. 2.

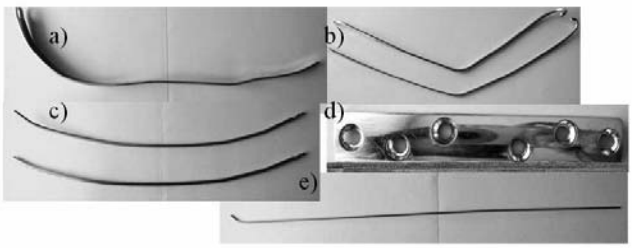

Fig. 1. Metallic implants for research: a) stabilization plate of the funnel chest, b) intramedullary Kirschner nails, c) intramedullary Ender nails, d) wide plate, e) intramedullary nail for children in the initial state

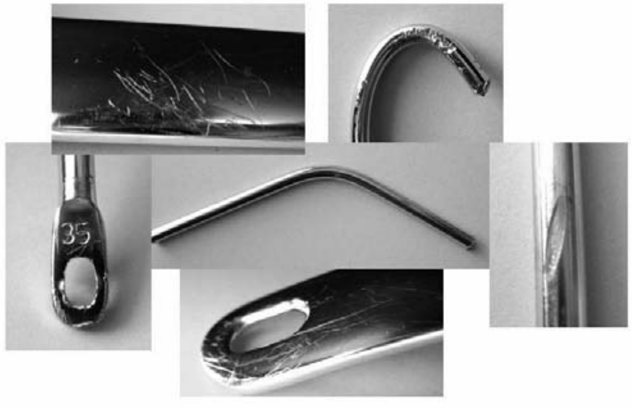

Fig. 2. Mechanical damages of implants' surface

Table 1.
Chemical composition of Tyrode's solution [1]

Solutions composition	Concentration, g/l
$NaHCO_3$	0.5
NaH_2PO_4	0.025
$MgCl_2*6H_2O$	1
KCl	1
$CaCl_2$	0.1
NaCl	40

The corrosion resistance investigations were based on the potentiodynamic tests in which the anodic polaryzation curves were recorded. The VoltaLab PGP 201 system for electrochemical tests was used. The corrosion potential of the samples was polarized up to the potential for which the current intensity reached 1 mA. The tests were performed in the Tyrode's physiological solution at the temperature of 37±1ºC and pH = 7.4 – Table 1.

3. Results

The samples with the largest mechanical surface damages were separated on the basis of macroscopic observations. The deep, long scratches arised in result of surgical instruments manipulation, in order to adapt the implants geometry to anatomical shape of joint fractions.

These damages could be also formed during removing implants from the body. The largest damages were observed in area near screw holes and at the ends of implants. The surface roughness of nails and wires didn't exceed the limit value of Ra = 0.16 µm. For stabilization plates of the funnel chest Ra exceeded the limit value and was equal to 0.59 µm. The majority of samples didn`t exceed the limit value of the surface roughness.

On the basis of research the values of corrosion potential E_{corr} were defined. There were determined the values of breakdown potentials E_b and repassivation potential E_{cp} during the recording of the anodic polarization curves. The change of polarization direction didn`t cause the decrease of current density. The hysteresis loop on the polaryzation curves was observed.

Microscopic observation after corrosion resistance tests revealed the presence of corrosion pits on the samples surface.

Table 2.
Results of pitting corrosion tests

Gr.[1]	Kind of implant	Implantation time	E_{corr}, mV	E_{rp}, mV	E_b, mV
I	Intramedullary Kirschner wires-end w/d[2]	9 weeks	+57	-147	+964
	Intramedullary Kirschner wires-end	9 weeks	+51	+133	+596
	Intramedullary Kirschner wires - middle	9 weeks	+50	+111	+793
II	Intramedullary Ender nails – end w/d	6 months	+48	+81	+911
	Intramedullary Ender nails – end with hole	6 months	+65	+45	+907
	Intramedullary Ender nails – middle	6 months	+45	+176	+774
	Wide plate – end w/d	6 months	+70	+170	+585
	Wide plate – middle	6 months	+52	-215	+549
	Stabilization plate of the funnel chest - end	35 months	+48	-31	+930
	Stabilization plate of the funnel chest - middle	35 months	-78	-37	+628
	Stabilization plate of the funnel chest – middle w/d	35 months	+103	-60	+623
	Stabilization plate of the funnel chest - end	36 months	+21	+136	+686
	Stabilization plate of the funnel chest - end	36 months	+56	+135	+607
	Stabilization plate of the funnel chest – middle w/d	36 months	+41	-17	+1017
III	Intramedullary Kirschner wires for children - end	–	+49	+126	+845
	Intramedullary Kirschner wires for children - middle	–	-143	-125	+718

[1]research's group
[2]w/d without damages

For the first group of implants the corrosion potential was in the range of E_{corr} = +50 – +57 mV, however the breakdown potential was in the range of E_b = +596 – +964 mV. For the second group of implants after 6 – 36 months of implantation the corrosion potential was in the range of E_{corr} = -78 – +103 mV, and the breakdown potential was in the range of E_b = +549 – +1017 mV. For the intramedullary nails in the initial state the corrosion potential was E_{corr} = -143 – +49mV, however the breakdown potential was in the range of E_b = +718 – +845 mV – Table 2.

The differences in the values of breakdown potentials were the consequence of amount and extent of mechanical damages. It can be stated that the corrosion potential was increasing with the breakdown potential. The values of breakdown potential were also increasing with the time of implantation. It was probably caused by the components of physiological solution which created the passive layer on the implants surface. It can influence positively the increase of corrosion resistance. High values of the breakdown potentials performance of good corrosion resistance of Cr-Ni-Mo austenitic stainless steel. The smallest values of breakdown potentials after implantation were registered in areas of the largest mechanical surface damages.

After comparison of the results of research of the intramedullary wires after implantation and in the initial state it can be said that for implants in the initial state there hadn`t been registered high values of the breakdown potentials.

4. Conclusions

Potentiodynamic research in Tyrode's physiological solution gave information about corrosion resistance of implants made of Cr-Ni-Mo steel before and after implantation. The breakdown potentials values were in the range +549 – +1017mV. Mechanical surface damages in the form of long and deep scratches were the places of initiation corrosion pits. Evolution of pitting corrosion depended on amounts and size surface damages and on implantation time. Concluding, prebending should be done properly, with the use of dedicated tools. No significant differences of breakdown potentials for the intramedullary wires in the initial state and after implantation were observed. This indicates that mechanical damages, caused by the implantation procedure, is passivated in body fluids. So despite of the damages of the implants surface they present good corrosion resistance.

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