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Corrosion resistance of NiTi alloy in simulated body fluids

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ABSTRACT

Purpose: Corrosion resistance of an implant alloy is a very important determinant of its biocompatibility. The nature of an environment and surface treatments have a significant influence on corrosion. Most of the knowledge on the corrosion behavior of NiTi is from studies of "standard" corrosion tests. In fact, the knowledge of the corrosion behavior of NiTi inside the body is very limited. The main aim of the research was evaluation of corrosion resistance of NiTi alloy in various simulated body fluids.

Design/methodology/approach: The evaluation of the electrochemical behavior of NiTi alloy was realized by recording of anodic polarization curves with the use of the potentiodynamic method. The tests were carried out for differently modified surfaces in diverse simulated body fluids.

Findings: Surface condition of a metallic biomaterial determines its corrosion resistance. In the course of the work the good corrosion resistance of all the tested samples (with different surface conditions) was observed.

Research limitations/implications: The obtained results are the basis for the optimization of physicochemical properties of the NiTi alloy. The future research should be focused on selected specific implants specially with respect to their application features.

Practical implications: On the basis of the obtained results it can be stated that the suggested surface treatment can be applicable for NiTi alloys due to the increase of the corrosion resistance.

Originality/value: The paper presents the influence of various methods of the surface treatment on corrosion resistance of the NiTi alloy. The suggested surface treatment methods can be applied to implants intended for diverse medical applications, especially in cardiology and urology.

Keywords: Biomaterials; Metallic material; Corrosion; Potentiodynamic tests; Simulated body fluids

MATERIALS

1. Introduction

Stainless steels, titanium alloys and cobalt alloys are commonly used as biomaterials [1-7]. Nowadays NiTi shape memory alloys are also introduced to clinical practice. The major advantage of these biomaterials refers to their unique properties, i.e. a thermal shape memory effect and a superelasticity. When shape memory alloys are considered as candidates to be applied in medical devices, they must be able to fulfill functional requirements related not only to their mechanical reliability but also to their chemical reliability (in vivo degradation, decomposition and dissolution, corrosion, etc.) and their biological reliability (biocompatibility, cytotoxicity, carcinogenicity, anti-thrombogenicity, antigenicity, etc.). A great body of research was done to understand the mechanical and physiochemical properties to this extraordinary biomaterial and introduce it to clinical practice [8-15].

2. Material and methods

The corrosion tests were carried out on NiTi alloy intended for implants. The chemical composition of the alloy (Ni – 55,5%, Ti – balance) met the requirements of the ASTM 2063 standard. The tests were carried out on samples in the form of a flat bar (length l = 21 mm, width w = 16 mm and thickness equal to 1 mm). In order to evaluate the influence of diverse methods of surface modification on the corrosion resistance of the alloy, the following surface treatments were applied:

- electropolishing – previously ground samples (#800) were electropolished in the HF-based solution worked out by the author. Current densities were in the range 5 – 50 A/dm^2,
- passivation – the passivation process was carried out in boiling water for 1 hour,
- deposition of carbon layer – the carbon layer was deposited with the use of RF PCVD (Radio Frequency Plasma Chemical Vapour Deposition) process.

The main aim of the research was determination of corrosion resistance of NiTi samples of modified surfaces in simulated body fluids, appropriate from the point of view of clinical practice. The following simulated body fluids were selected :

- Tyrode's physiological solution,
- artificial urine,
- artificial plasma.

Chemical composition of the selected body fluids is presented in table 1.

Table 1.
Chemical composition of the selected body fluids

Simulated body fluid	Components	Concentration, g/l
Tyrode's solution	NaCl	8,0
	$CaCl_2$	0,2
	KCl	0,22
	$NaHCO_3$	1,0
	NaH_2PO_4	0,05
	$MgCl_2$	0,2
artificial urine	$CaCl_2H_2O$	1,765
	Na_2SO_4	4,862
	$MgSO_47H_2O$	1,143
	NH_4Cl	4,643
	KCl	12,130
	$NaHPOH_2O$	6,8
	$NaHPO_4$	0,869
	Na_3H_2O	1,168
	NaCl	13,545
artificial plasma	NaCl	6,8
	$CaCl_2$	0,2
	KCl	0,4
	$NaHCO_3$	2,2
	NaH_2PO_4	0,026
	$MgSO_4$	0,1
	Na_2HPO_4	0,126

The electrochemical tests of the investigated alloy were performed with the use of a potentiodynamic method by recording of anodic polarization curves. In the tests the scan rate was equal to 1 mV/sec. The PGP 201 potentiostat with the software for electrochemical tests was applied. The saturated calomel electrode (SCE) was applied as the reference electrode and the auxiliary electrode was a platinum foil. The exposed area of the specimen was equal to 1 cm^2. The scanning direction was reversed when the anodic current density reached 100 μA/cm^2.

3. Results

3.1. Corrosion resistance of the samples tested in Tyrode's solution

Results of corrosion resistance of the NiTi samples tested in the Tyrode's solution were presented in fig. 1 and table 2.

For the electropolished samples the average corrosion potential was equal to E_{corr} = - 106 mV. Sudden increase of the anodic current density was observed for the transpassivation potential equal to E_{tr} = 1222 mV. The average repassivation potential was equal to E_{rp} = 1382 mV.

For the passivated samples the average corrosion potential reached E_{corr} = - 106 mV. The value of the transpassivation potential was equal to E_{tr} = 1292 mV. The average repassivation potential was equal to E_{rp} = 1394 mV.

For the samples with carbon layer the mean value of the corrosion potential was equal to E_{corr} = - 111 mV. The samples were characterized by the highest value of the transpassivation potential equal to E_{tr} = 1496 mV. The average repassivation potential was equal to E_{rp} = 1191 mV.

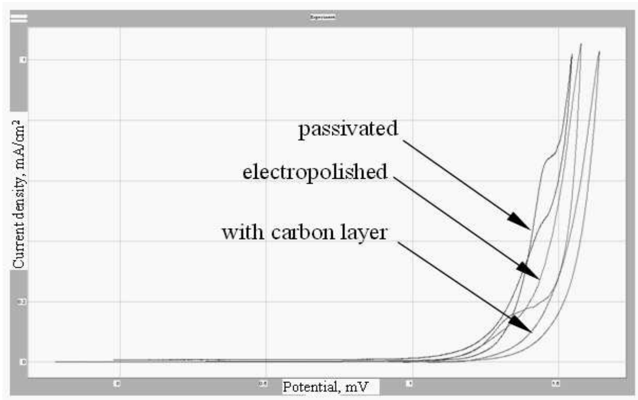

Fig. 1. Potentiodynamic curves of the samples tested in the Tyrode's solution

Table 2.
Corrosion resistance of the comparative samples tested in the Tyrode's solution

surface	$E_{corr.}$, mV	$E_{tr.}$, mV	$E_{rp.}$, mV
electropolished	- 106	1222	1382
passivated	-106	1292	1394
with carbon layer	-111	1496	1191

3.2. Corrosion resistance of the samples tested in artificial urine

Results of corrosion resistance of the NiTi samples tested in the artificial urine were presented in fig. 2 and table 3.

For the electropolished samples the average corrosion potential was equal to E_{corr} = - 200 mV. Sudden increase of the anodic current density was observed for the transpassivation potential equal to E_{tr} = 1222 mV. The average repassivation potential was equal to E_{rp} = 1387 mV.

For the passivated samples the average corrosion potential reached E_{corr} = - 188 mV. The value of the transpassivation potential was equal to E_{tr} = 1245 mV. The average repassivation potential was equal to E_{rp} = 1179 mV.

For the samples with carbon layer the mean value of the corrosion potential was equal to E_{corr} = - 136 mV. The samples were characterized by the highest value of the transpassivation potential equal to E_{tr} = 1316 mV. The average repassivation potential was equal to E_{rp} = 1420 mV.

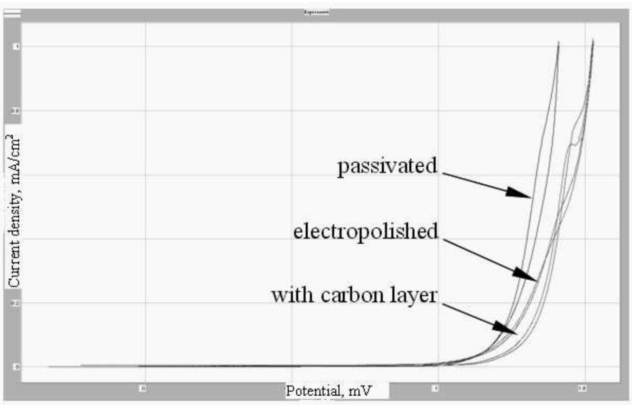

Fig. 2. Potentiodynamic curves of the samples tested in the artificial urine

Table 3.
Corrosion resistance of the comparative samples tested in the artificial urine

surface	$E_{corr.}$, mV	$E_{tr.}$, mV	$E_{rp.}$, mV
electropolished	-200	1222	1387
passivated	-188	1245	1179
with carbon layer	-136	1316	1420

3.3. Corrosion resistance of the samples tested in artificial plasma

Results of corrosion resistance of the NiTi samples tested in the artificial plasma were presented in fig. 3 and table 4.
For the electropolished samples the average corrosion potential was equal to E_{corr} = - 33 mV. Sudden increase of the anodic current density was observed for the transpassivation potential equal to E_{tr} = 1216 mV. The average repassivation potential was equal to E_{rp} = 1327 mV.

For the passivated samples the average corrosion potential reached E_{corr} = - 126 mV. The value of the transpassivation potential was equal to E_{tr} = 1400 mV. The average repassivation potential was equal to E_{rp} = 1548 mV.

For the samples with carbon layer the mean value of the corrosion potential was equal to E_{corr} = - 153 mV. The samples were characterized by the highest value of the transpassivation potential equal to E_{tr} = 1307 mV. The average repassivation potential was equal to E_{rp} = 1156 mV.

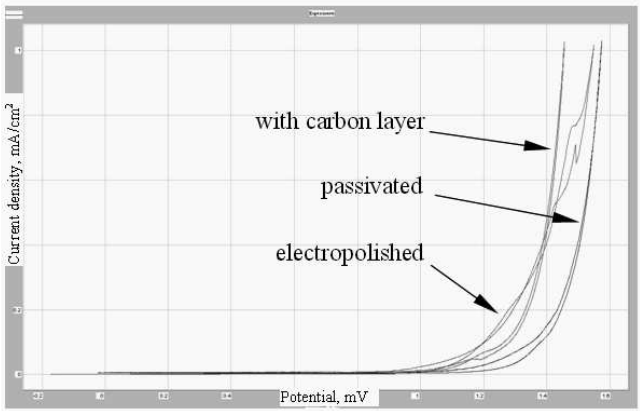

Fig. 3. Potentiodynamic curves of the NiTi samples tested in the artificial plasma

Table 4.
Corrosion resistance of the comparative samples tested in the artificial plasma

surface	$E_{corr.}$, mV	$E_{tr.}$, mV	$E_{rp.}$, mV
electropolished	-33	1216	1327
passivated	-126	1400	1548
with carbon layer	-153	1307	1156

4. Conclusions

The aim of the research was determination of corrosion resistance of the NiTi samples with modified surfaces in diverse simulated body fluids. The research was carried out in the Tyrode's physiological solution, the artificial urine and the artificial plasma.

The electrochemical tests carried out in the Tyrode's solution revealed that all the suggested surface modifications ensure good corrosion resistance. The mean values of the corrosion potential, the transpassivation potential and the repassivation potential of the tested samples was equal to E_{corr} = - 107 mV, E_{tr} = 1336 mV and E_{rp} = 1322 mV respectively.

The electrochemical tests carried out in the artificial urine did not reveal significant changes of the corrosion resistance with reference to the samples tested in the Tyrode's solution. The mean values of the corrosion potential, the transpassivation potential and the repassivation potential of the tested samples was equal to E_{corr} = - 175 mV, E_{tr} = 1261 mV and E_{rp} = 1328 mV respectively.

The corrosion resistance tests carried out in the artificial plasma also did not revealed the decrease of the corrosion resistance with respect to the samples tested in the Tyrode's solution and the artificial urine. The mean values of the corrosion potential, the transpassivation potential and the repassivation potential of the tested samples was equal to E_{corr} = - 104 mV, E_{tr} = 1307 mV and E_{rp} = 1344 mV respectively.

The research revealed that the proposed surface modifications of the NiTi alloy ensure good corrosion resistance in the selected body fluids. On the basis of the obtained results it can be stated that the suggested surface treatment can be used for implants applied in cardiology and urology.

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