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Corrosion behaviour of metallic biomaterials used as orthodontic wires

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Properties

ABSTRACT

Purpose: The aim of the work was evaluation of the corrosion resistance of the commercial metallic orthodontic wires from different manufacturers in simulated intra-oral environment.
Design/methodology/approach: Corrosion resistance tests were carried out in artificial saliva at the temperature 37±1°C with the use of the VoltaLab® PGP 201 system for electrochemical tests. The saturated calomel electrode (SCE) was applied as the reference electrode and the auxiliary electrode was a platinum foil. The evaluation of pitting corrosion was realized by recording of anodic polarization curves with the use of the potentiodynamic method. In order to evaluate crevice corrosion resistance the samples were polarized in the potential equal to 0.8 V by 900 seconds.
Findings: Results of corrosion resistance tests of the CrNi, NiTi and CuNiTi wires showed comparable data of parameters obtained in the artificial saliva.
Research limitations/implications: The obtained results show the influence of artificial saliva on the electrochemical corrosion of orthodontic wires. In order to demonstrate the higher risk of corrosion, which can have two consequences: a loss of the physical properties and the release of Ni ions (which have been shown to be toxic and the cause of allergic reactions) - additional research on fatigue corrosion should be carried out.
Originality/value: The analysis of the obtained results show that that commonly used materials for making orthodontic wires (because of their interesting properties - elasticity and shape memory) can be used in different orthodontic treatment stages to correct numerous clinical conditions. The most favorable characteristics were observed for the new NiTi samples (American Orthodontics).
Keywords: Corrosion; Working properties of materials and products; Metallic materials; Biomaterials

1. Introduction

Among alloy applied in orthodontics (for making orthodontic wires), four alloys are in common use: titanium alloys (NiTi and CuNiTi), stainless steel alloys, cobalt-chromium alloys and β-titanium alloys. The elasticity and shape memory of each of these types of wires means that they can be used in different orthodontic treatment stages to correct numerous clinical conditions. Mentioned alloys are numbered among biomaterials of good biocompatibility [1-5]. In recent years the increase of biocompatibility is realized by formation of surface layers. It is connected with biological activity of implanted metals and their corrosion [6-17]. The corrosion behavior of orthodontic wires is a decisive factor determining their biocompatibility. And their mechanical properties and corrosion resistance are determined by chemical composition and the technology of production as well. The deterioration of the corrosion resistance of orthodontic wires has two consequences. The first is a loss of the physical properties which play in the success of the clinical treatment. The second is the release of nickel ions - it is obvious that in nickel-base alloys the main element present in corrosion products is undoubtedly nickel. Unfortunately, nickel ions release from these alloys have been shown to be toxic and the cause of allergic reactions [4,5].

2. Materials and methods

The aim of the work was evaluation of corrosion resistance of the commercial metallic orthodontic wires from different manufacturers and different times of remaining in the buccal cavity (from material in the initial state to 14th months maximally). The applied materials met the standard requirements concerning chemical composition, structure and mechanical properties [18].

Corrosion tests were performed in the simulated intra-oral environment – artificial saliva – at the temperature of 37±1 °C. The composition of this solution – closely resembles natural saliva – is presented in Table 1.

The electrochemical tests of the investigated wires were performed with the use of the potentiodynamic method by recording of anodic polarization curves (*i=f(E)*). The PGP 201 potentiostat with the software for electrochemical tests was applied [19,20]. The saturated calomel electrode (SCE) was applied as the reference electrode and the auxiliary electrode was a platinum foil. The polarization curves and Stern-Geary relationship were used to determine the corrosion current density (i_{corr}) and the polarization resistance (R_p) at the end of corrosion potential exposure. Then corrosion rate (v_{corr}) of wires in test solution was calculated. The experiments were performed five times for each orthodontic wire. After corrosion test one specimen of each materials were observed using a OPTON DSM 940 scanning electron microscope.

3. Results

3.1. Initial state

For the wires in the initial state the obtained values of the transpassivation potentials revealed the significant difference. The lowest values were observed for the CrNi wires of the GAC International (E_{tr} = +190 – +200 mV) and the highest ones for the NiTi samples of the American orthodontics (E_{tr} = +1370 – +1388 mV) – Table 2, Fig. 1 and Fig. 4. The values of the polarization resistance changed considerably also. The lowest values of polarization resistance were observed for the CuNiTi wires of the Ormco (R_p = 213 – 233 kΩcm) (Fig.1) and NiTi for the GAC International after 14 months of remaining in the buccal cavity (R_p = 380 – 399 kΩcm). However, for the NiTi (Ormco) the values of the polarization resistance were comparable (R_p = 410 – 424 kΩcm) (Fig. 2 and 3). The recorded curves revealed the passive region, in spite of CrNi and CuNiTi samples. The values of current density showed a significant differences. The lowest values were observed for the NiTi wires (i_{corr} = +6.50 – +10.02 nA/cm^2) and the highest ones for the CuNiTi samples of the Ormco Corporation (i_{corr} = +117.18 – +120.60 nA/cm^2) – Table 2.

Table 1.
Chemical compositions of artificial saliva used in investigations

Ingredients	Concentration, g/dm^3
NaCl	6.70
KSCN	0.33
KCl	1.20
$NaHCO_3$	1.50
NaH_2PO_4	0.26
KH_2PO_4	0.20

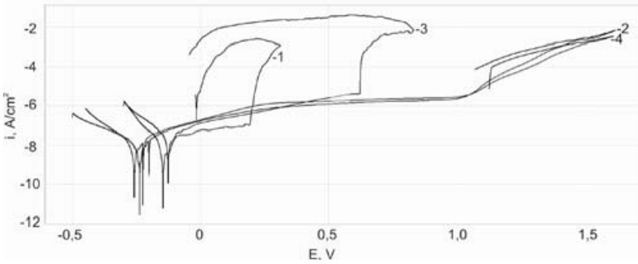

Fig. 1. Anodic polarization curves for orthodontic wires in the initial state: 1 – CrNi (GAC International), 2 – CuNiTi (Ormco Corporation), 3 – CrNi (American Orthodontics), 4 – NiTi (American Orthodontics)

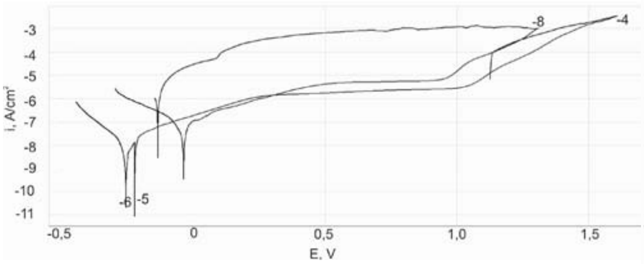

Fig. 2. Anodic polarization curves of NiTi orthodontic wires: 4 – American Orthodontics, initial, 5 – GAC International, 14 months, 6 – Ormco Corporation, 13 months, 8 – American Orthodontics, 3 months

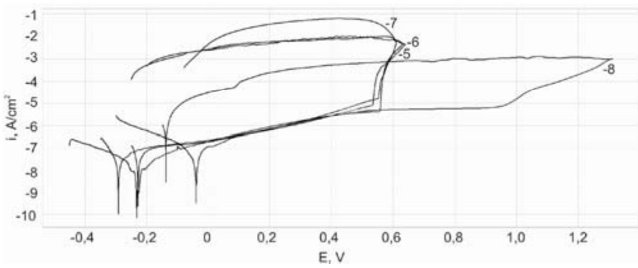

Fig. 3. Anodic polarization curves for orthodontic wires: 5 – NiTi (GAC International, 14 months), 6 – NiTi (Ormco Corporation, 13 months), 7 – CrNi (American Orthodontics, 6 months), 8 –NiTi (American Orthodontics, 3 months)

Table 2.
Results of pitting corrosion resistance in artificial saliva

Samples				Corrosion potential E_{corr}, mV	Transpassivation potential E_{tr}, mV	Corrosion current density i_{corr}, nA/cm^2	Polarisation resistance R_p, kΩcm^2	Corrosion rate v_{corr}, µm/year
No	Material	Manufacturer	Time of remaining in buccal cavity					
1	CrNi	GAC International	Initial	-140 – -150	+190 – +200	38.62 – 42.01	635 – 650	0.46
2	CuNiTi	Ormco Corporation	Initial	-227 – -236	+1272 – +1285	117.18 – 120.60	213 – 233	1.35
3	CrNi	American Orthodontics	Initial	-125 – -131	+618 – +630	43.06 – 47.01	560 – 572	0.52
4	NiTi	American Orthodontics	Initial	-250 – -258	+1370 – +1388	6.50 – 10.02	4000 – 4005	0.07
5	NiTi	GAC International	14 months	-230 – -235	+550 – +560	63.82 – 66.00	380 – 399	0.76
6	NiTi	Ormco Corporation	13 months	-289 – -293	+540 – +556	60.70 – 67.01	410 – 424	0.72
7	CrNi	American Orthodontics	6 months	-64 – -70	+560 – +570	58.17 – 62.45	420 – 432	0.70
8	NiTi	American Orthodontics	3 months	-40 – -50	+1210 – +1220	61.75 – 66.02	421 – 434	0.71

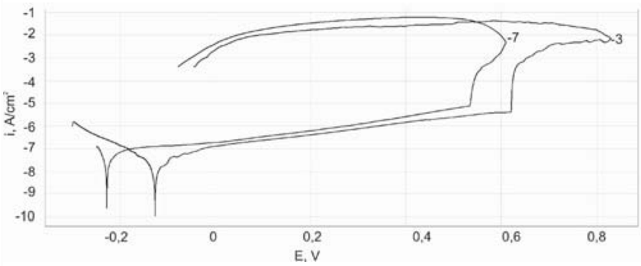

Fig. 4. Anodic polarization curves for CrNi orthodontic wires (American Orthodontics): 3 – in the initial state, 7 – 6 months clinical treatment

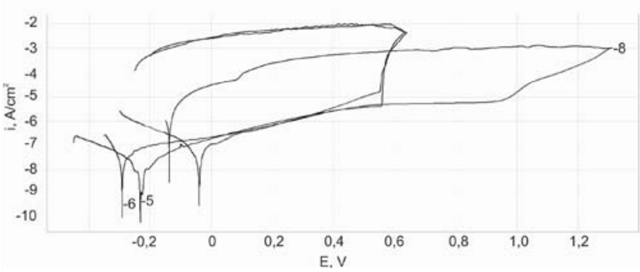

Fig. 5. Anodic polarization curves for NiTi orthodontic wires : 5 – GAC International, 14 months, 6 – Ormco Corporation, 13 months, 8 – American Orthodontics, 3 months

3.2. Retrieved archwires

The lowest corrosion potential values were reached for the NiTi samples (Ormco Corporation) retrieved after 14 months of clinical treatment (E_{corr} = -289 – -293 mV), and the highest for the NiTi samples (American Orthodontics) tested after 3 months of the treatment (E_{corr} = -40 – -50 mV). The recorded curves revealed the passive region.

On the basis of the recorded anodic polarization curves, for the retrieved archwires, significant differences in the transpassivation potentials were observed – Fig. 3. The lowest values were in the range E_{tr} = +540 – +556 mV and the highest in the range E_{tr} = +1210 – +1220 mV – Fig. 5.

However, the values of the polarization resistance did not changed considerably. The lowest values of the polarization resistance were observed for the NiTi archwires of the GAC International (R_p = 380 – 399 kΩcm^2), and the highest ones also for the NiTi archwires (R_p = 421 – 434 kΩcm^2) – but from American Orthodontics manufacturer.

Regardless of the time of remaining in the oral cavity, values of the current density were comparable. The values of the current density and the corrosion rate are presented in Table 2.

4. Conclusions

Corrosion resistance of metallic biomaterials is one of the basic criteria determining their usefulness. In the presented work, the authors focused on pitting corrosion of CrNi, NiTi and CuNiTi alloys – the most commonly used for making orthodontic wires. All of these alloys are considered to be compatible with the body – their biocompatibility is based on their corrosion resistance.

The attraction of the austenitic stainless steel is that its highly malleable and so can be readily shaped for a wide variety of purpose. Moreover, they offer lower resistance to tooth movement than other alloys. Their corrosion resistance is comparable to that of beta-titanium wires, however, they produce also lower levels of frictional resistance.

Regardless of the applied alloys for archwires - their geometrical form, where the shape is determined by the manufacturer using thermo mechanical processing – mechanical deformation at elevated temperature. The research revealed insignificant influence of the applied clinical time of treatment on the corrosion resistance of the analyzed alloy. It is highly important consideration for orthodontic archwires, since the release of significant quantities of metallic ions (especially Ni) might have adverse effects on the health of patients.

The analysis of the pitting corrosion showed comparable data of parameters obtained in the artificial saliva, that's why all variants of the applied alloys ensure good crevice corrosion resistance. The most favorable corrosion characteristics is observed for the new NiTi material (American Orthodontics) – it was found to be the most resistant.

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