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Experimental Study of Changes in the Electric Potential of Implants Made of Titanium Alloys under the Influence of Functional Dynamic Load.

Egor Evgenyevich Olesov , Igor Aleksandrovich Shugailov, Marsel Zakeevich Mirgazizov, Mariya Mikhailovna Pozharitskaya, and Semen Aleksandrovich Zaslavskii.

Training Institute of the Federal Medical and Biological Agency, Russia, 125371, Moscow, Volokolamsk highway, 90.

ABSTRACT

Dental implants are mainly made of titanium and are in constant contact with a metal frame covering the crowns, which does not preclude contact electrochemical reactions affecting the condition of the surrounding tissues. The study aims to develop methods and to obtain experimental data measuring the electric potential of titanium alloys for intraosseous implants in their dynamic loading. Two alloys were studied – titanium nickelide alloy with a shape recovery effect and VT1-0 brand titanium. For the experiment, a stand was designed for loading implants in artificial saliva environment. It was found out that the electrochemical response of titanium nickelide alloy and titanium to the load in a biological environment is identical and is characterized by a temporary decrease in corrosion resistance due to the damage of the surface protective films. However, the electrochemical behavior of titanium nickelide alloy is more favorable as it is characterized by a gradual (rather than abrupt) decrease in electric potential and a lower amplitude reduction. The obtained results are important for the clinic of dental implantology, as the temporary and slight decrease in the corrosion resistance of titanium implants under dynamic loading is revealed. In the clinic conditions, the damages of the surface oxide film of dental implants are possible, which can significantly enhance the electrochemical reactions, and therefore require further experimental and clinical studies.

Keywords: implant, titanium, titanium nickelide alloy, load, corrosion.

Corresponding author

INTRODUCTION

The development of ideas about the biomechanical compatibility of structural dental materials and prosthetic bed tissues causes the growing interest of researchers in the detailed physical, mechanical and electrochemical characteristics of metal alloys used in prosthetic dentistry and implantology. Modern alloys used for casting frames of removable and fixed dentures and producing dental implants are characterized by the high corrosion resistance, strength, and biological inertness. High parameters of these characteristics are particularly inherent in titanium (Gileva *et al.*, 2012; Zhusev, 2012; Kulakov *et al.*, 2006; Nikholskiy *et al.*, 2015; Babbush *et al.*, 2010; Block, 2010; Debnath, & Debnath, 2014; Greenberg, 2015; Misch, 2014; Renvert, & Giovannoli, 2013; Romanos, 2012; Shafie, 2007).

However, the deformation properties of metal alloys that appear in multiple loads to dentures dramatically differ from the deformation behavior of body tissues (teeth, paradontium, and bone tissue) that could cause their overload and development of undesired consequences (inflammation, atrophy).

At the end of the last century in dentistry, particularly in implantology, a new material emerged – the titanium nickelide alloy, which in connection with the property of super elasticity was able to friendly work with the supporting tissues of dental prostheses and implants (Gruzinov *et al.*, 2009; Gyunter, 2010; Kairbekov, 2012; Kostin, & Kalamkarov, 2016; Medvedev *et al.*, 2010, 2016; Kuznetsov *et al.*, 2016).

The interest in this material increases, but not all of its features are fully understood, and therefore the relevant studies using different methodological approaches and modern research equipment are required. In particular, the object of the study was to compare the dynamics of electric potentials of the titanium-nickelide and titanium implants surfaces under the influence of cyclic load.

METHODOLOGY

To conduct electrochemical measurements in dynamic load, the patterns of titanium nickelide (NiTi) and titanium VT1-0 of 40 mm long and 0.5 mm in diameter were used. A biological solution (artificial saliva) and Hank's solution at pH ~ 7 under t = 37 °C (Table 1) were used as a medium.

Table 1. Composition of model solutions.

Model corrosive medium (mass fraction)	Medium pH
Biological solution 0.4% KCl, 0.4% NaCl, 0.795% $CaCl_2$, 0.69% Na_2HPO_4, 0.005% $Na_2S{\cdot}9H_2O$.1% urea	7
Hank's solution 80% NaCl, 4% KCl, 1.4% $CaCl_2$, 3.5% Na_2HCo_3, 0.6% $Na_2HPO_4{\cdot}2H_2O$, 6% KH_2PO_4, 0.6% $MgSO_4{\cdot}7H_2O$, 1% $MgCl_2{\cdot}6H_2O$.1% glucose	7.2

The electrochemical characteristics of the alloys were measured using an electronic potentiostat PS-7 in the stand with continuous automatic recording of the electrochemical parameters through the method of potentiodynamic polarization with the potential sweep rate of 2 mV/s. For the measurement, a three-electrode cell with a split electrode space was used, which, to maintain the desired temperature of the solution, was placed in the ultratermostat UTU-4 filled with work fluid. Temperature maintenance accuracy is ± 1 °C.

The samples in the form of wire were used as test objects due to the fact that the wire as well as dental implants made of the study alloys have a cylindrical shape, and hence close load distribution. To conduct electrochemical measurements, a portion of the polished surface with the area of about 2 cm was used; the rest part was isolated with a chemically resistant lacquer.

The dynamic loads on the samples of titanium nickelide and titanium of 1,000 MPa were applied by means of engineered stand, which made it possible to create forces on the sample directly within the model solution (Figure 1).

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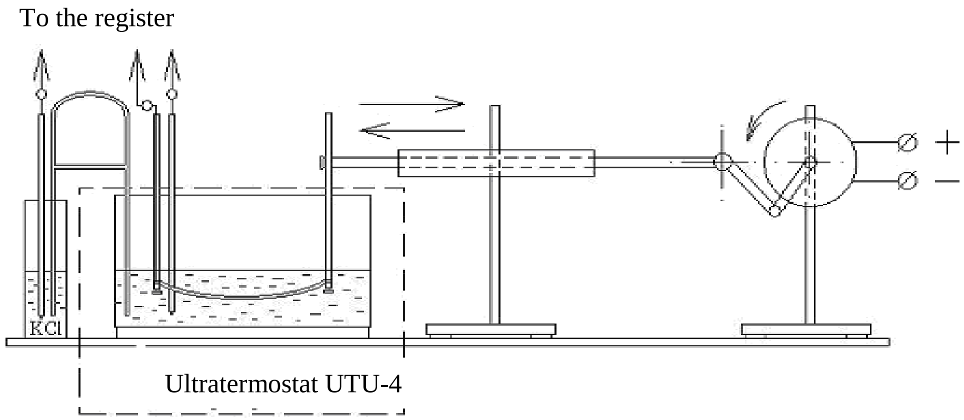

Figure 1. Stand scheme for studying the effect of dynamic loads on the electric potential of NiTi and Ti.

The principle of operation of this stand is as follows: a sample in the form of wire was fixed on the two vertical bars – fasteners made of non-conductive material, namely, Plexiglass and placed in a bath with guides to exclude the possibility of its bending in more than one direction. One of the bars was rigidly fastened to a stationary tripod, while the second was attached to the rod, which in turn, through the guide tube, was powered by an SD-054 type motor (collector type) by means of a crank mechanism. A load rate varied by changing the voltage applied to the electric motor by means of a laboratory transformer, and the value of stresses – by changing the arm of crank mechanism. The value of operating voltage was calculated from the equation used in the two-point bending of samples. The load value was calculated according to the equation change in the value of the sample's bending arc.

The equation used to calculate the value of load at the two-point bend of samples

$$s = \frac{4 \times E \times f \times h}{l^2 + 4 \times f^2},$$

where σ is the value of load, N/mm^2,
E is the Young's modulus, N/mm^2,
f is the bending arc, mm,
l is the distance between supports, mm,
h is the sample width, mm.

In carrying out kinetic studies, the following method was used: degreasing of the sample surface, immersing it in the model solution, measuring the open-circuit potential until their reaching the steady-state value, then when exposed to periodic dynamic load for 20 minutes (one meal) and after removing the load until the establishment of steady mode.

By the method of electron scanning microscopy using SEM HITACHI S-800, the fractures of work sample made of titanium nickelide and titanium alloys were examined, which were destroyed under the influence of a periodic dynamic load in a biological environment.

RESULTS

Simulation of functional loads caused at the start of load an abrupt displacement of the stationary electric potential of TiNi (as well as titanium) to the negative direction. The offset value and its subsequent change in the exposure under cyclic loading determines the mechanical stability of the passivation films and their ability to recover after a local failure. In the absence of load, film is recovered by the action of corrosive environment and is destroyed again when the load is resuming.

The offset value of the NiTi electric potential in a solution simulating human saliva is 70 mV; the period of the potential reduction lasts 100 minutes, wherein the initial value of the electric potential is restored within 20 minutes and is characterized by the following minor fluctuations (Figure 2). In the Hank's solution, which has less oxidizing power, the electric potential offset occurs by a large value of 100 mV and for a more extended period of 25 minutes, followed by retaining low potential values for 2.5 hours and then restoring them to the original values after another 3 hours (Figures 2, 3).

Electric potential of titanium in the biological solution under the load application is abruptly decreased by 65 mV and recovered after several fluctuations during 25 minutes. In the Hank's solution, an abrupt decrease in potential makes 180 mV, it is maintained during 2 hours, and is restored to the initial values after 3 hours.

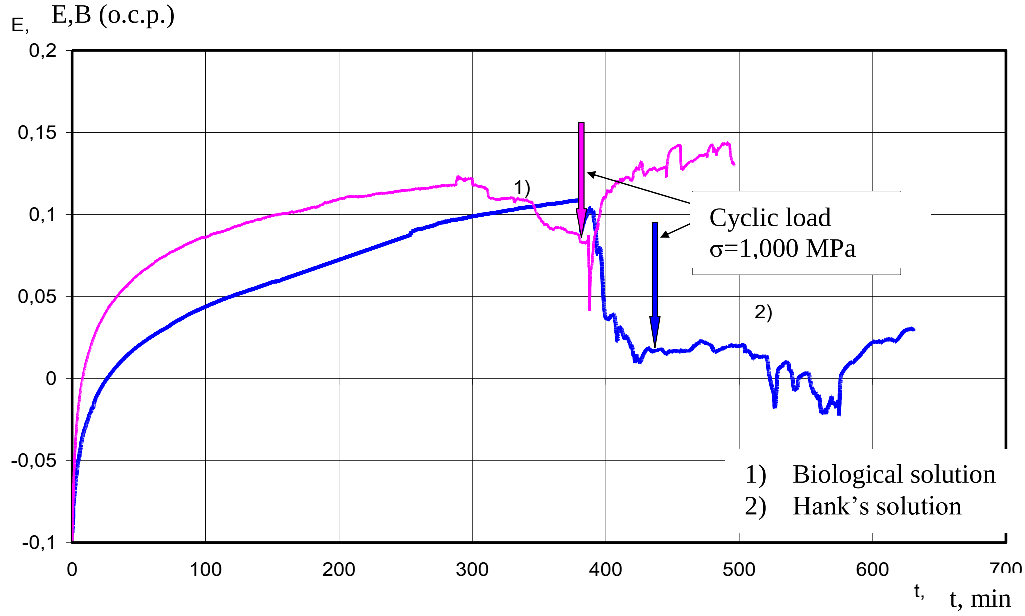

Figure 2. The dependence of the open-circuit potential of the implant surface (NiTi) on the exposure time in biological solutions at a temperature of 37 °C and when exposed to load: a – NiTi; b – VT1-0.

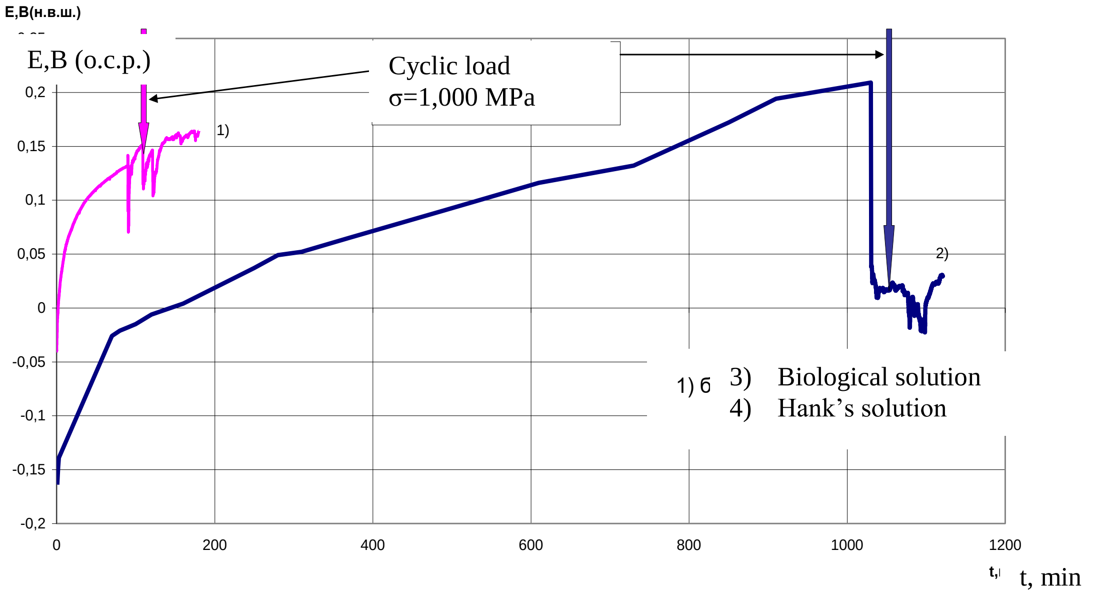

Figure 3. The dependence of the open-circuit potential of the implant surface (VT1-0) on the exposure time in biological solutions at a temperature of 37 °C and when exposed to load.

In the study of the fracture surface micrographs of the NiTi samples after staying in a corrosive environment, the destruction mechanism can be characterized: the center of the structure assumes a viscous nature of the fracture, a more crystallized peripheral – a brittle fracture that differentiates titanium nickelide alloy from the titanium destruction mechanism accompanied by intermittent irregular zones of gradual ductile and brittle fracture under the action of the corrosive medium (Figures 4, 5).

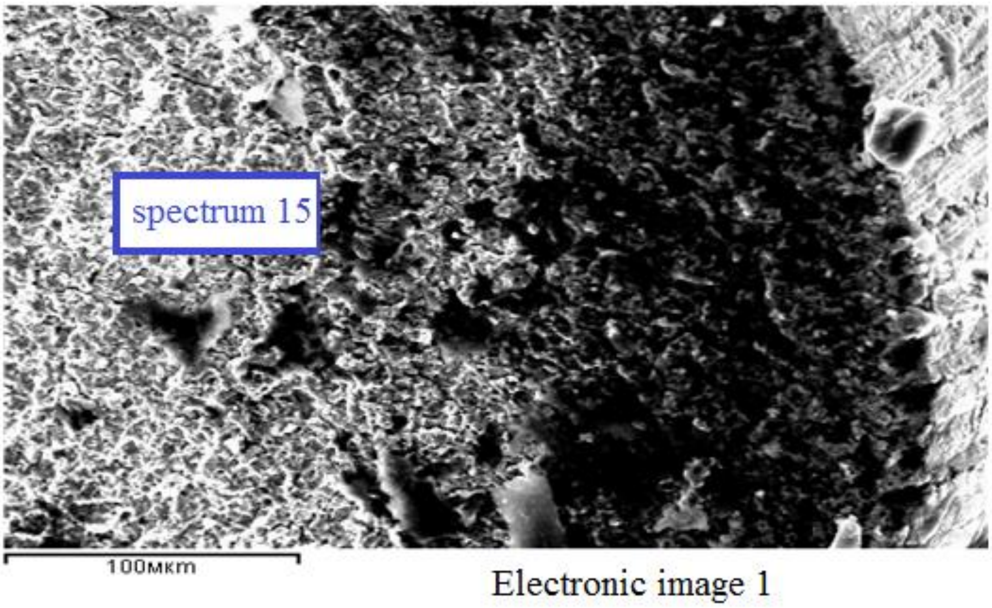

Figure 4. The microstructure of the NiTi implant fracture.

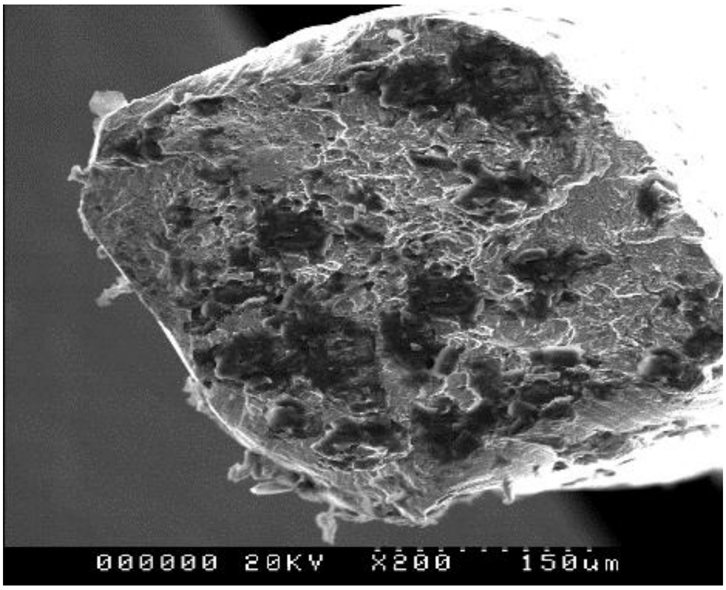

Figure 5. The microstructure of the VT1-0 implant fracture.

DISCUSSION

Thus, the electrochemical response of titanium nickelide and titanium to the load of prosthetic constructions in the biological environment is identical and is characterized by a temporary drop in corrosion resistance performance in connection with the violation of the surface protective films, but with a load of NiTi it is characterized by gradual (rather than abrupt) decrease in electric potential, smaller amplitude of potential reduction in a solution with a low oxidizing ability.

The studies confirm a higher elasticity of NiTi as compared to titanium, which is essential for biomechanical and electrochemical processes at implant loads.

CONCLUSION

For the first time in the experimental implantology, a cyclic change in the value of electric potentials of the surface of titanium implants is registered, which corresponds to the application and removal of functional load on the implant. Changing the electric potentials is associated with the damage of oxide film on the titanium surface. These changes are less pronounced in NiTi with the shape recovery effect. Amid the intermittent chewing load and in the presence of heterogeneous alloys in the oral cavity, the toxic chemical phenomena in mouth are not excluded, which requires targeted clinical studies.

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