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Comparative corrosion study of Ti–Ta alloys for dental applications

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Abstract

Besides other important material features, the corrosion parameters and corrosion products are responsible for limiting the biocompatibility of metallic materials, and can produce undesirable reactions in implant-adjacent and/or more distant tissues. Titanium and some of its alloys are known as being the most biocompatible metallic materials due to their high strength, low modulus, high corrosion resistance in biological media, etc. More recently, Ti–Ta alloys have been developed, and these are expected to become more promising candidates for biomedical and dental applications than commercially pure Ti, Ti–6Al–4V or Ti–6Al–7Nb alloy. The corrosion behavior of the studied Ti–Ta alloys with Ta contents of 30, 40, 50 and 60 wt.% together with the currently used Ti–6Al–7Nb alloy were investigated for dental applications. All alloys were tested by open-circuit potential measurement, linear polarization, potentiodynamic polarization, coulometric zone analysis and electrochemical impedance spectroscopy performed in artificial saliva with different pH, acid lactic and fluoride contents. The passive behavior for all the titanium alloys is observed for artificial saliva, acidified saliva (9.8 $g\,l^{-1}$ lactic acid, pH 2.5) and for fluoridated saliva (1.0 $g\,l^{-1}$ F^-, pH 8). A decrease in corrosion resistance and less protective passive oxide films are observed for all titanium alloys in fluoridated acidified saliva (9.8 $g\,l^{-1}$ lactic acid, 1.0 $g\,l^{-1}$ F^-, pH 2.5) in regard to other electrochemical media used within this work. It is worthy of note that the most important decrease was found for Ti–6Al–7Nb alloy. These conclusions are confirmed by all the electrochemical tests undertaken. However, the results confirm that the corrosion resistance of the studied Ti–Ta alloys in all saliva is better or similar to that of Ti–6Al–7Nb alloy, suggesting that the Ti–Ta alloys have potential for dental applications.

Keywords: Ti–Ta alloys; Corrosion resistance; Potentiodynamic polarization; Dental application

1. Introduction

Nowadays, the medical applications of biomaterials have been diversified, and once medical applications were widened the term biocompatibility received new meanings, and it has been obviously redefined. In the sense of this new definition [1], a biomaterial must have the ability to allow the device or construct made from it to perform the function for which it was designed. This must happen under certain constraints [1]: (i) any undesirable local or systemic effects, (ii) the most appropriate host response, and (iii) optimizing the clinical performance of the therapy. To satisfy these constraints, the development of new materials with desired bulk and surface properties was one of the solutions adopted by researchers and specialists [2–17]. When a long-term implantable device is designed, the following bulk and surface properties of biomaterials need to be considered [1,13–29]: bulk and superficial chemical composition, structure, morphology, surface topography, surface energy, mechanical properties, electric and magnetic properties, corrosion resistance, degradation resistance, etc. Among the materials used to make long-term

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implantable devices, metallic materials are more suitable for load-bearing applications, osteosynthesis, stents, heart valve prosthesis, dental implants, crowns and bridges, etc. Among the metallic biomaterials, titanium and its alloys have become some of the most attractive biomaterials to make orthopedic implants, dental implants, and other devices for dental applications due to their low density, high specific strength, elastic modulus close to that of bone tissue, and superior corrosion resistance in body fluids [16–29]. All this results in that these metallic materials have a good biocompatibility. However, the possibility of corrosion in titanium-based materials used for medical and dental applications remains a major concern, especially due to the local and systemic effects of corrosion products [20–28].

In the early use of metal alloys as biomaterials, lack of biocompatibility was extensively reported, and research on improved materials with appropriate biocompatibility was developed. Commercially pure titanium (cp-Ti, ASTM F-67, ISO 5832-2) was used for medical and dental applications, and the Ti–6Al–4V alloy was the first titanium alloy registered as an implant material (ASTM F-1472, ASTM F-136, ISO 5832-3) [2,3]. Subsequently, concerns about the potential cytotoxicity of vanadium and its adverse reaction with the human body, as well as the possible formation of oxides harmful to the human body as a result of in vivo degradation by different mechanisms [2,3,8,12,13,20,21], have encouraged the search for new titanium-based biomaterials to replace Ti–6Al–4V [2,3,5,8,20], such as Ti–6Al–7Nb (ASTM F-1295, ISO 5832-11) and Ti–5Al–2.5Fe (ISO 5832-10). It has been suggested by Kobayashi et al. [19], and Lavos-Valereto and Wolynec [30] that Ti–6Al–7Nb might be a better alternative to Ti–6Al–4V because of its better corrosion resistance, and the replacement of V with non-toxic Nb. Moreover, there have been concerns, not yet confirmed, about the association between aluminum and Alzheimer's disease [28,29]. More recently, Ti–Mo [3,9,11,23–25], Ti–Nb [3,9,26], Ti–Ta [5–7,10,16,22], Ti–Zr [12] and Ti–Hf [10,31] binary alloys have been developed, and these are expected to become promising candidates for biomedical and/or dental applications due to alloying with non-toxic elements, and their better mechanical compatibility with bone tissue than cp-Ti and Ti–6Al–4V alloy [8]. Both NaF and other fluoride compounds are frequently used as prophylactic products in dental treatments to prevent plaque formation and caries development [4,24,32–45]. It is already known that dental hygiene products containing fluoride ions can attack the oxide film formed on the titanium surface, which suggests the existence of problems regarding the dental use of titanium and its alloys [39,41,43–45]. Tantalum has chemical properties similar to glass, namely it is immune to attack by almost all acids except for concentrated HF [46]. Lactic acid is naturally released by bacteria in the oral cavity [47]. In this scenario, it is important to investigate the corrosion resistance of these new titanium alloys as a function of both the lactic acid and fluoride content of the electrochemical medium.

The aim of this study was to investigate the corrosion resistance of Ti–Ta alloys with 30, 40, 50 or 60 wt.% Ta contents in different simulated oral media, in view of the dental applications of these alloys. For comparative purposes, the same measurements were also performed on Ti–6Al–7Nb alloy.

2. Materials and methods

2.1. Materials

The origin and nominal chemical compositions of the titanium alloys studied are shown in Table 1. The Ti–6Al–7Nb samples were obtained from a 12 mm diameter bar stock in annealed state. The Ti–6Al–7Nb secondary melting ingot was forged within the $\alpha-\beta$ domain, then annealed and air cooled. The ingots from Ti–Ta alloys (diameter = 10 mm, length = 20 mm) were obtained by levitation melting in a high-frequency induction furnace with a cold copper crucible. In order to eliminate the segregation, the homogenization heat treatment was performed in a tubular furnace using the following heat treatment conditions: (1) homogenization temperature range, β-transus temperature +100 °C, (2) heating rate, 5 °C min^{-1}, and (3) natural cooling. Both microstructural analysis and corrosion test specimens were machined from Ti–6Al–7Nb bar and homogenized Ti–Ta alloy ingots.

2.2. Structural characterization

The phase analysis of Ti–Ta alloys was carried out by X-ray diffraction (XRD) using a Philips PW 1830 diffractometer operated at 40 kV and 30 mA with Cu $K\alpha_1$ radiation.

The microstructures of all the samples and the specimens' surfaces exposed for electrochemical testing were also studied using a metallographic microscope (XJP-6A, Material Plus software). For structural analysis the samples were prepared by polishing using emery paper up to 2500 grit and final mirror polishing with 0.3 μm alumina suspension, which was succeeded by appropriate etching.

Table 1
The origin and the nominal chemical compositions of titanium alloys.

Alloy	Nominal chemical composition (wt.%)	Supplier
Ti–6Al–7Nb	Ti: base, Al: 6, Nb: 7	R&D CS[a]
Ti–30Ta	Ti: 70, Ta: 30	INSA, Rennes[b]
Ti–40Ta	Ti: 60, Ta: 40	INSA, Rennes
Ti–50Ta	Ti: 50, Ta: 50	INSA, Rennes
Ti–60Ta	Ti: 40, Ta: 60	INSA, Rennes

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