Biocompatible medical implants elaborated from nitrided titanium-based superelastic alloys

Phase 1

ABSTRACT

The widespread use of titanium (Ti) alloy in the field of implantology is due primarily to increased corrosion resistance and higher level of biocompatibility. However, not all Ti alloys meet the requirements for biomedical applications. This has attracted the development of a new group of Ti alloys such as Ti-Nb and Ti-Zr alloys that have recently been placed on the market in order to overcome the toxicity associated with Ti-V/Al alloys. In addition, since the biomaterial surface plays a critical role in cellular response, improved biological and tribological properties by changing the surface are often required. At this stage, nitriding of a superelastic beta-type Ti alloy in the system Ti-Nb-Ta-Zr was performed by our partner from INSA Rennes. The originality of the protocol is that the nitriding treatment is carried out simultaneously with the process of recrystallization observing the formation of a nitride layer of about several tens of micrometers on the alloy surface. The internal nitriding process has the advantage of maintaining excellent cohesion of nitride coating on the substrate, avoiding the delamination problems and fragility which are normally occurring when the hard ceramic coatings are deposited on metallic substrates.

Evaluation of passive film and resistance to bio-corrosion of the unprocessed and nitrided Ti-Nb-Ta-Zr was performed using the following methods: cyclic potentiodynamic polarization, linear polarization, electrochemical impedance spectroscopy - EIS. Cyclic potentiodynamic curves showed a passive behavior for both Ti, untreated alloy and nitrided alloy. There was noted a nobler behavior of the processed alloy as compared to untreated alloy and Ti. All electrochemical parameters for the nitrided alloy showed more favorable values by comparison with Ti and unprocessed alloy. This means that the nitriding process has significantly improved the strength of the passive film on the surface of nitrided alloy. Corrosion current densities, $i_{cor}$, the corrosion rate, $V_{cor}$, and the ion release for the nitrided alloy was about 10 times lower than those of Ti and about 2 times lower than those of the untreated alloy due to the fact that the nitride layer acts as a barrier against the transport of ions through it, greatly reducing the toxicity of the processed alloy. Impedance results showed the dual character of the nitrided alloy: resistance to bio-corrosion due to internal oxide layer and bioactivity due to the deposited outer layer. There have been developed equivalent open circuits for both unprocessed and nitrided alloys.

Chemical characterization of the alloy was realized by SEM, EDX and FT-IR studies.

The purpose of the biological studies has been to evaluate the alloys’ biocompatibility and the osteoblast response to untreated and nitrided surfaces of Ti-Nb-Ta-Zr alloy. The first objective was to achieve indirect contact cytotoxicity studies according to ISO 10993-5: 2009/ (R)2014 for biological evaluation of medical devices. Vero cells incubated in the extraction media of the analyzed alloys did not exhibit any morphological change, showed low levels of LDH released into the culture medium and a proliferation rate similar to the negative control. Direct contact studies with human osteoblasts in terms of adhesion and cellular morphology (double-labeling for focal adhesion kinase and actin filaments), viability (staining with calcein AM/ethidium bromide) and cell proliferation (MTT assay) showed that the nitrided superelastic beta-type Ti-Nb-Ta-Zr alloy sustained cell adhesion, survival and proliferation at a level approximately similar to the untreated alloy. These results together with the noble behavior in the corrosion studies recommend the nitrided alloy as a good candidate for bone implant.