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A comparative study of the cytotoxicity and corrosion resistance of nickel–titanium and titanium–niobium shape memory alloys

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ABSTRACT

Nickel–titanium (NiTi) shape memory alloys (SMAs) are commonly used in a range of biomedical applications. However, concerns exist regarding their use in certain biomedical scenarios due to the known toxicity of Ni and conflicting reports of NiTi corrosion resistance, particularly under dynamic loading. Titanium–niobium (TiNb) SMAs have recently been proposed as an alternative to NiTi SMAs due to the biocompatibility of both constituents, the ability of both Ti and Nb to form protective surface oxides, and their superior workability. However, several properties critical to the use of TiNb SMAs in biomedical applications have not been systematically explored in comparison with NiTi SMAs. These properties include cytocompatibility, corrosion resistance, and alterations in alloy surface composition in response to prolonged exposure to physiological solutions. Therefore, the goal of the present work was to comparatively investigate these aspects of NiTi (49.2 at.% Ti) and TiNb (26 at.% Nb) SMAs. The results from the current studies indicate that TiNb SMAs are less cytotoxic than NiTi SMAs, at least under static culture conditions. This increased TiNb cytocompatibility was correlated with reduced ion release as well as with increased corrosion resistance according to potentio-dynamic tests. Measurements of the surface composition of samples exposed to cell culture medium further supported the reduced ion release observed from TiNb relative to NiTi SMAs. Alloy composition depth profiles also suggested the formation of calcium phosphate deposits within the surface oxide layers of medium-exposed NiTi but not of TiNb. Collectively, the present results indicate that TiNb SMAs may be promising alternatives to NiTi for certain biomedical applications.

1. Introduction

Shape memory alloys (SMAs) have attracted considerable interest in the biomedical community due to their unique ability to recover their original shape upon heating after deformation and to respond elastically to relatively large strains [1]. These behaviors, known as the shape memory effect and superelasticity, respectively, provide powerful design tools unavailable in traditional metallic materials, such as stainless steel and conventional titanium (Ti) alloys. Nickel–titanium (NiTi) SMAs are among the most popular SMAs for biomedical applications, including stents or medical and dental wires, due to the relative ease of formability and improved fracture and fatigue resistance compared with other commercial SMAs [2]. However, several issues have limited the use of NiTi SMAs in a number of biomedical applications where the unique properties of SMAs could provide substantial benefits. Among the major concerns surrounding NiTi surgical implants is the known toxicity [3,4] and possibly carcinogenicity [5] of Ni. In addition, 4.5–8% of the general population is hypersensitive to Ni [6,7], which can result in allergic responses to implanted NiTi alloys. These issues have raised questions regarding the use of NiTi SMAs in certain biomedical applications due to the possibility of substantial Ni release into the body in the event of alloy damage, corrosion, or excessive surface wearing.

Like pure Ti, NiTi surfaces are composed primarily of passive TiO_2 layers, which render the alloy bio-inert and resistant to corrosion and Ni ion release [8]. Indeed, most in vivo and in vitro studies suggest that NiTi alloys are at least as biocompatible as pure Ti [3,8–11]. However, the stability of the TiO_2 layers of NiTi SMAs has recently been challenged by the results of several clinical and

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