Morphological Characterization and Corrosion Resistance of TiNi Foams for Biomedical Applications

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Statement of Purpose: The nearly equiatomic nickel titanium alloys have been widely used in the biomedical industry for their shape memory, superelasticity, and fatigue resistance properties. Despite these advantages, wider range of application of these alloys in the biomedical field has been hindered for a long time, owing to the lack of definite conclusions about their corrosion properties and nickel ion release (Assad M. Bio-Med Mat Eng 2002;12:225-37). Orthodontic wires and intravascular stents are at now produced using NiTi, and porous NiTi is under investigation for orthopedic devices. In fact, porous structure could promote osteointegration, as mechanical properties are similar to those of bone (Prymak O. Biomaterials 2005;26:5801-07). Presently, a new class of NiTi foams, produced via Self-Propagating High-Temperature Synthesis (SHS) method, has found a growing interest in the design of orthopedic devices.
In the present study the electrochemical properties of two TiNi foams, produced by Self-Propagating High-Temperature Synthesis (SHS) with different porosity and pore dimension, were evaluated. Moreover, the effects of selected chemical passivation treatments on the corrosion resistance and ion release were investigated.

Methods: Two NiTi foams (A=lot 032405L67S1 and B=lot 032405L67S2) were produced via SHS method from Shapechange Technologies LLC (SCT, CA, USA). Samples were cut by electroerosion technique and washed in ammonia (28% v/v) for 16h in ultrasonic bath to remove the contaminants introduced by the cutting procedure (control material). Four passivation treatments were performed on the foams: 1) HNO_3 (20% v/v), 20min, 80°C (PN20-80); 2) HNO_3 (20% v/v), 20min, 80°C in ultrasonic bath (PN20-80-US); 3) HNO_3 (20% v/), 2h, 40°C in ultrasonic; 4) mechanically polished, HNO_3 (20% v/v), 20min, 80°C (PL). The foams characterization was performed by stereomicroscopy (Wild M8), SEM (Zeiss EVO50), volume variation picnometer, XRD (Philips PW1830), DSC (Seiko 6200). Electrochemical properties were evaluated by potentiodynamic and potentiostatic tests, and nickel ion release tests (BS EN ISO 10993).

Results/Discussion: Pore dimension was highly variable (A: 100-600μm, B: 200-1000μm), but showing a good pore interconnection (Fig.1).

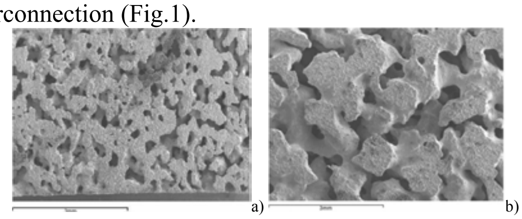

Figure 1. SEM images of a) NiTi A, and b) NiTi B

Table 1. Transformation temperature and ΔH of NiTi A and NiTi B foams

		A_s [°C]	A_f [°C]	M_s [°C]	M_f [°C]	ΔH [mJ/mg]
NiTi A foam	Step 1	87	128			7,3
	Step 2			62	36	- 9,5
	Step 3	74	100			9,1
NiTi B foam	Step 1	82	118			9,2
	Step 2			63	39	-12,9
	Step 3	75	101			9,9

XRD analysis showed the presence of the characteristic peaks related to austenitic phase, martensitic and intermetallic Ti_2Ni. According to DSC analysis, the two NiTi foams exhibited shape memory effects (Table 1).
Potentiodynamic tests were performed to evaluate localized corrosion. PN20-80-US sample showed the best results (E_{bk}=155mV, Fig.2). Potentiodynamic behavior of NiTi A and B foams was similar. In potentiostatic tests, TiNi A PN20-80-US showed lower currents throughout all the test time, compared to the control sample.

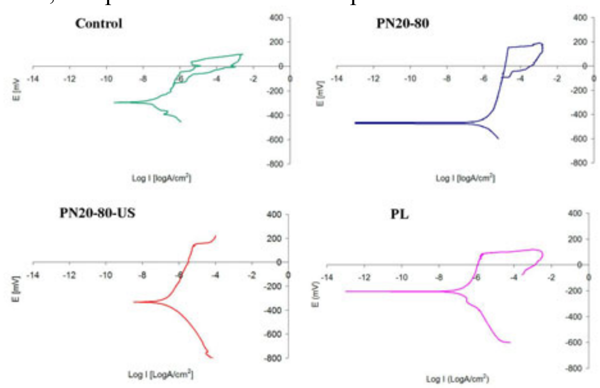

Figure 1. Potentiodynamic curves for control and treated NiTi A

Nickel ion release was 29.3 ppb and 225 ppb, respectively for NiTi A PN20-80-US and control samples. The difference results were attributed to the formation of a more compact passivity film on the surface of the treated sample.

Conclusions: The TiNi foams obtained via SHS showed good corrosion resistance properties, that can be further improved via chemical passivation treatments. Moreover, by high temperature annealing, it should be possible to smooth out some of the sharp points present in the foams, allowing for better potentiodynamic performance. The two different foams can be produced with a high percentage of open porosity, comparable with the trabecular bone porosity, and therefore they appear interesting candidates for orthopedic applications Further *in vitro* studies on cytotoxicity and cells/materials interactions are in progress.

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