Ni release from rapid prototyped 3D NiTi scaffolds

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INTRODUCTION: The shape memory alloy nickel-titanium is a promising biomaterial for load-bearing implants, exhibiting pseudo-elastic behavior and allowing for mechanical stimulation of adherent cells and adjacent tissues, thus improving the osseo-integration.[1] For a metal, NiTi has a low elastic modulus minimizing the effect of stress-shielding.[2] However, Ni release from NiTi implants remains a significant concern as its toxic effects have been linked to increased levels of oxidative stress found within cells.[3] With the ultimate goal of fabricating porous implants intended for load-bearing sites, NiTi substrates were fabricated by means of selective laser melting (SLM), and the release of Ni ions was assessed.

METHODS: Fig. 1 represents a NiTi scaffold built by means of SLM (Realizer 100, SLM-Solutions, Germany) using NiTi powder (Memry GmbH, Germany). To mimic physiological loading conditions, uniaxial dynamic compression was applied toscaffolds using a servo-hydraulic testing machine (walter+bai AG, Switzerland) with a sinusoidal loading profile, 100 µm displacement amplitude and a frequency of 8 Hz. During the loading cycles, Ni release from NiTi scaffolds was supported via continuous, recirculating perfusion with PBS solution (0.3 ml/min). Samples for Ni release measurements were taken at 24h (690'000 cycles), 1 week ($4.8x10^6$ cycles) and 2 week time points ($9.6x10^6$ cycles). The Ni amount was assessed by atom absorption spectroscopy (AAS, Perkin Elmer, AAnalyst 800, graphite furnace, 232 nm).

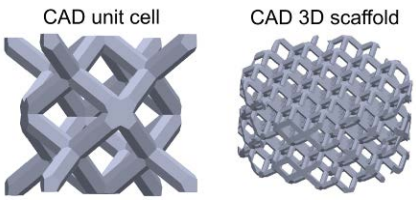

Fig. 1: CAD illustration of the unit cell and the cylindrical SLM-NiTi scaffold (4 mm height and 8 mm diameter).

RESULTS: The AAS measurements reveal Ni release in both loaded and unloaded conditions. The mechanically loaded NiTi scaffolds demonstrated a significantly higher Ni release within the first 24h. Thereafter only small, time-dependent increases were detected. However, at all time points, the levels of released Ni ions were below the cytotoxic level for fibroblastic cells.[4]

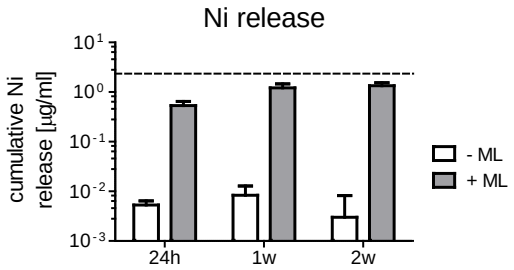

Fig. 2: Cumulative Ni release for unloaded (-ML) and loaded (+ML) NiTi scaffolds. Dashed line depicts cytotoxic Ni ion level[4].

DISCUSSION & CONCLUSIONS: Unloaded SLM NiTi constructs show minimal Ni ion release. Upon application of physiological loads, cracks may form in the titanium oxide layer on the NiTi surface. Due to the rupture of the protective oxide layer, Ni ions are released into the perfusate. The Ni concentrations determined in this study remain under the cytotoxic level of 2.35 µg/mL[4]. Surface treatments could further improve the inertness of NiTi constructs. Moreover, under in vivo conditions, NiTi implants are continuously flushed by the bloodstream minimizing local Ni ion concentrations even further. Furthermore, MSC have been shown to colonize loaded SLM-NiTi scaffolds with no signs of cytotoxic effects[5].

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