Hydroxyapatite crystal thickness and orientation at the bone implant interface : spatial and temporal evolutions

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HYDROXYAPATITE CRYSTAL THICKNESS AND ORIENTATION AT THE BONE IMPLANT INTERFACE: SPATIAL AND TEMPORAL EVOLUTIONS

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Introduction

Bone structure is complex and evolves over time, especially during osseointegration, when bone forms around and onto an implant surface. Sufficient bone ingrowth together with adequate quality, depending on its compositional, structural and mechanical properties, will condition the long-term stability of the implant. The nanoscale arrangement and reorganization is of particular interest since a relationship between mineral crystals thickness and elastic properties of bone tissue has been observed [1]. Thus, characterizing crystal thickness around an implant may help to evaluate the mechanical properties of the interface. but only little work is available [2, 3]. We investigated spatial and temporal evolutions of crystal thickness and orientation close to a metallic implant using small angle x-ray scattering (SAXS); this work has been published [4].

Methods

Samples. Eight New Zealand male rabbits had their tibiae implanted with a standardized implant model (coin-shaped, titanium, Ø5mm, L3mm) composed of a flat interface and a chamber for bone to grow into (Fig. 1 top). After 7 (n=4) and 13 weeks (n=4) of healing time, the rabbits were euthanized and samples were embedded into PMMA, cut transversally and polished to ~100µm-thick slices to expose the interface.

Scanning SAXS was conducted at the cSAXS beamline, SLS, PSI, using a microfocus setup with x-ray energy of 12.4keV and 100ms exposure time. The whole ingrowth chamber and a mature bone region were mapped with a pixel size of 5µm and a step size of 5µm.

Data analysis was conducted using Matlab routines. Crystal thickness was calculated from the radial integration of scattering intensity (I(q)) profiles and orientation from the azimuthal integration (I(ψ)) using established protocols [4]. Thickness and orientation were averaged in 10µm-thick lines from the interface to investigate their spatial evolution.

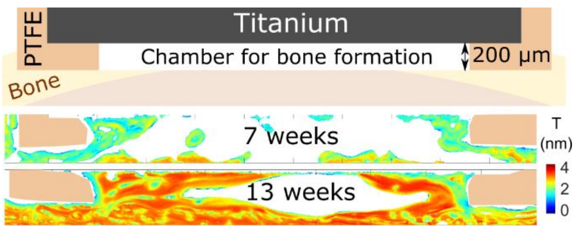

Figure 1: Standardized implant model (top) and crystal thickness (T) mapping of newly formed bone after 7 and 13 weeks of osseointegration.

Results

Crystal are thinner in the bone chamber compared to mature regions (Table 1). Moreover, within the chamber, crystals are thinner after 7 compared to 13 weeks of healing time (Fig. 1) with a larger variation of the thicknesses at 13 weeks. Close to the implant surface, crystals are thinner and appear more aligned to the surface than further into the chamber.

T (nm)	Chamber	Mature
7w	1.79±0.45	2.52±0.31
13w	2.4±0.57	2.75±0.35

Table 1: Average crystal thickness (T) in nm of newly formed (chamber) and mature bone.

Discussion

Crystal thickness has been shown to be correlated to crystal volume [5] and can thus be used as a representative parameter of the evolution of the crystal size. The increased thickness with osseointegration is coherent with observed increase in bulk bone with maturation [1] and the larger spread of values at 13 weeks may reflect combined processes of bone ingrowth and bone remodeling, with both thin crystals being formed and large crystals being remodeled in more mature regions. Thinner crystals close to the interface confirm previous results [2], and could be linked to reduced mechanical loading, which is in agreement with our model. Further investigation on loaded interfaces and mechanical testing could help clarify if thick crystals at the interface are representative of higher strength. The tendency of crystals to align to the interface is consistent with previous results [3], but will be further investigated in the bone longitudinal direction, where fibers alignment is more pronounced.

References

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