NEUTRON TOMOGRAPHY AND IN SITU MECHANICAL TESTING TO CHARACTERIZE THE BONE-IMPLANT INTERFACE

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Summary: We assessed the feasibility of neutron tomography to image the interface between bone and a metallic implant. We first compared the image quality to the state-of-the art X-ray tomography and then combined it with in situ mechanical loading followed by Digital Volume Correlation (DVC) to identify bone damage and fracture.

1. INTRODUCTION

Metal implants are used for many orthopaedic conditions, *e.g.* in artificial joints or fracture fixation. The long-term stability of an implant requires new bone formation, that grows towards the implant and integrates it to the surrounding bone. High-resolution imaging combined with mechanical testing are of interest when evaluating bone-implant constructs and in improving their stability. X-ray tomography is commonly used to image bone, but causes artefacts in the immediate surrounding of a metallic implant. On the contrary, neutrons interact weakly with metal, and thus represent an interesting alternative to image the bone-implant interface. However, neutron tomography (NT) has hardly been explored for bone. By tracking texture between a first image (reference image) and a second deformed image, DVC can be used to calculate the internal displacement fields, and subsequently the internal strain fields of the bone close to the screw during loading. In this study, we investigated the potential of NT to image the bone-implant interface by comparing it to the X-ray counterpart, and to evaluate the possibility to characterize the mechanical response of the bone-implant interface by identifying damage and fracture during in situ pull-out.

2. MATERIALS AND METHODS

Metal screws were implanted transversely in rats' tibiae and osseointegrated during 4-6 weeks. Animals were sacrificed and tibiae with screws were dissected. One sample was imaged with 5 different tomography setups using either X-rays or neutron radiation (Table 1). Microstructural parameters were measured in a same ROI in the trabecular bone and the bone ingrowth around the implant was quantified if possible (no artefacts). Two other samples were loaded under neutron imaging at ICON, SINQ, PSI [1] (27 µm voxel size). The screws were pulled-out in displacement control with steps of 0.2 mm using a custom made loading device. A first neutron scan was acquired at sample contact with a preloading of 5N, and subsequent scans were realized every 0.2mm increments until rupture (Figure 1B). On the unloaded scans, the screw was masked using ImageJ to quantify the bone ingrowth around the implant. DVC was applied between the loaded steps using the in-house code TomoWarp2 [2], after post-processing the images in Kiptool using an implementation of the inverse scale space filter (ISS) for 3D data [3].

Table 1 - Scanning parameters applied to a same sample

	X-rays			Neutron	
Instrument	In vivo small animal scanner nanoScan, Mediso	State-of-the-art lab-scanner Zeiss Xradia XRM520		ICON beamline, SINQ, PSI, Switzerland	
Energy/Flux	65kV	160kV		$3x10^7$ neutrons cm^{-2} s^{-1}	
Scanning time	20 min	2 h	18 h	5 h	19 h
Voxel size	21µm	25µm	5µm	27µm	13µm

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3. RESULTS & DISCUSSION

Despite using relatively high energy, the metal implant induced artefacts in the X-rays images close to the metal screw, which was not observed in the neutron images, thus allowing analysis of bone ingrowth (Figure 1A). The microstructure quantification away from the implant agreed well among all imaging techniques, except for the neutron low-resolution scan, where the detailed trabeculae structure was difficult to visualize. The vertical displacements obtained with DVC on the 2 loaded samples are consistent with the experimental applied displacements. DVC identified localized shear strains and positive volumetric strains at the crack zones, coherent with a crack opening (Figure 1C).

The study serves as a proof-of-concept that neutron tomography may be used to image bone, and may be especially interesting in studies including metal components. No image artefacts were observed in the neutron images close to the interface. DVC enabled identification of the fracture directions, through high strain localizations. Only few samples and loading steps were performed due to the long scanning time and low neutron flux. Thus, this pilot study needs to be extended to more loading steps and more samples, before damage and fracture mechanisms can be accurately identified. However, it showed the feasibility of using neutron tomography in combination with mechanical testing to study the bone-implant interface.

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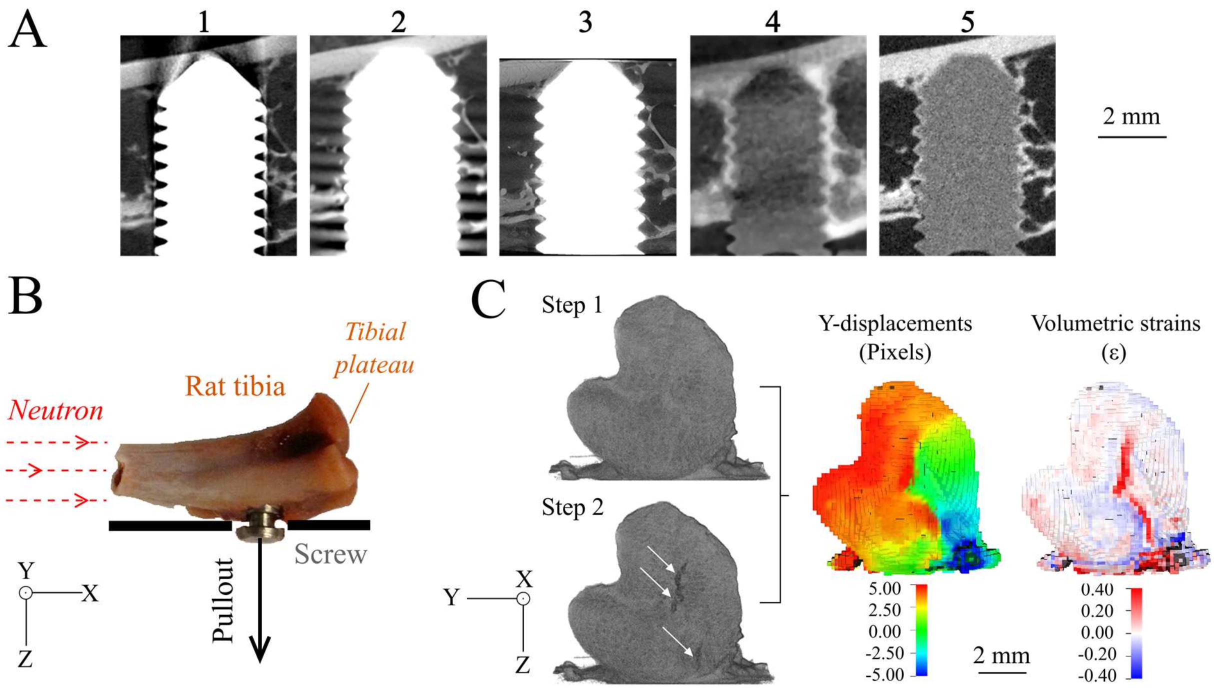

Figure 1: (A) Comparison of X-rays (1-3) and NT of a sample (1: in vivo 21μm voxel size, 2-3: Xradia 26μm-5μm, 4-5: neutron 27μm-13μm). (B) Schematic of the loading experiments. (C) 3D-views of one sample's tibial plateau with tomographic images (cracks highlighted in white arrows) and DVC results for the first two loading steps.