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# Analysis of Bone-Implant Integration with Synchrotron X-ray Tomography

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## Introduction

Proper integration of orthopedic implants within the host bone is a fundamental requirement for their successful function and limited risk of implant failure. Implant fixation is highly dependent on the amount and quality of the bone formed around the implant post-surgery. Calcium sulfate/hydroxyapatite cement (CaS/HA) can be used to locally administer bioactive molecules improving bone formation<sup>2</sup>. Synchrotron X-ray tomography (SR-CT) while *in situ* loading is a powerful tool to study the failure mechanisms surrounding implants at the microscale<sup>1</sup>. However, implants generally consist of a heavy metal or alloy, leading to X-ray image artefacts directly at the surface of the implant. Polyether ether ketone (PEEK) is a biocompatible material more similar to bone. It has been used, for example, for spinal cages. PEEK does not suffer from metal artefacts in the images, allowing to examine the bone-implant interface in greater detail<sup>2</sup>.

The aim of this study is to analyze the failure mechanisms of peri-implant bone at the microscale. Additionally, the effect of biomodulation on these mechanisms is investigated.

## Materials and methods

Hollow, PEEK screws were inserted in 15 rat tibiae (Fig 1A). CaS/HA was injected in a chamber inside the implants, without (Ctrl, n=7) or with (Trtd, n=8) the bioactive molecules rhBMP-2 and zoledronic acid, to accelerate bone growth. After 6 weeks of healing, the proximal tibiae containing the implants were excised.

The tibiae were imaged using SR-CT (TOMCAT, PSI, Switzerland) (energy: 30 keV; speed: ~2 min/scan; isotropic voxel size: 2.75  $\mu$ m). Initially, the specimens were imaged unloaded, to calculate the bone volume/total volume (BV/TV) around the screws. Later, the implants were pulled out *in situ* at 0.3 mm/min, and simultaneously imaged at 0.15 mm increments during holding phases (Fig. 1A).

From the load curves, the peak force, peak displacement, stiffness, and fracture energy were obtained. The mechanical parameters were compared between the two groups. Linear regression analysis was performed between each of the parameters and BV/TV. The 3D images were visually inspected to identify when and where cracks initiated.

Table 1: Structural and mechanical parameters for Control vs Treated specimens (mean (SD)).

Parameter	Ctrl	Trtd	p-value
BV/TV [%]	15 (6)	52 (15)	0.001
Peak force [N]	62 (28)	92 (30)	0.13
Peak displ. [ $\mu$ m]	466 (90)	620 (238)	0.13
Stiffness [N/mm]	151 (42)	173 (70)	0.46
Frac. energy [Nmm]	7.3 (4.5)	30 (15)	0.02

## Results and discussion

In the group treated with bioactive molecules, a higher BV/TV was measured around the implants (Table 1) as well as a higher fracture energy during pullout. No differences were observed for the remaining mechanical parameters. A positive correlation was found between BV/TV and fracture energy (Fig. 1B).

The bone in the threads of the implants is clearly visible thanks to the use of PEEK implants which circumvents image artefacts. Cracks developing in this region can be seen during early loading, well before global failure (Fig. 1C).

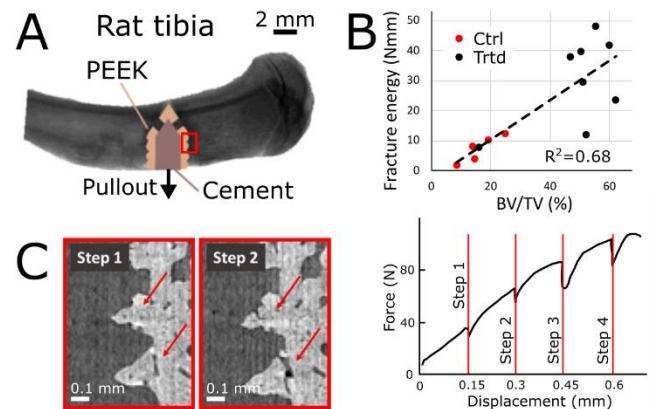


Fig. 1 A) Setup for *in situ* pullouts. B) Correlation between BV/TV and fracture energy for the Ctrl and Trtd groups. C) SR-CT images of cracks forming during the pullout and the force-displacement curve of a treated specimen.

## Conclusion

*In situ* SR-CT pull-outs of bone integrated PEEK implants can be used to study the failure mechanisms of newly formed interfacial bone tissue. Such methodology enables high-resolution visualization of the damage in peri-implant bone. The failure mechanisms specific to the Ctrl and Trtd groups will be further investigated before the conference.

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