



HAL
open science

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

J Kok, Törnquist E., Lohéac O., Sophie Le Cann, Raina D.B., Tägil M.,
Novak V., Engqvist J., Isaksson H.

► **To cite this version:**

J Kok, Törnquist E., Lohéac O., Sophie Le Cann, Raina D.B., et al.. Analysis of Bone-Implant Integration with Synchrotron X-ray Tomography. Quantitative Musculoskeletal Imaging (QMSKI) 2022 &, Jun 2022, Noordwijk, Netherlands. hal-04044592

HAL Id: hal-04044592

<https://amu.hal.science/hal-04044592>

Submitted on 24 Mar 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

Kok J.^{1,2}, Törnquist E.^{1,3}, Lohéac O.¹, Le Cann S.³, Raina D.B.¹, Tägil M.¹, Novak V.⁴, Engqvist J.¹, Isaksson H.¹

¹ Lund University, Sweden

² Eindhoven University of Technology, Netherlands, j.kok@tue.nl

³ CNRS, Université Paris-Est Créteil, France

⁴ Paul Scherrer Institute, Switzerland

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 formation². Synchrotron X-ray tomography (SR-CT) while *in situ* loading is a powerful tool to study the failure mechanisms surrounding implants at the microscale¹. 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 detail².

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 μm). 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. [μm]	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).

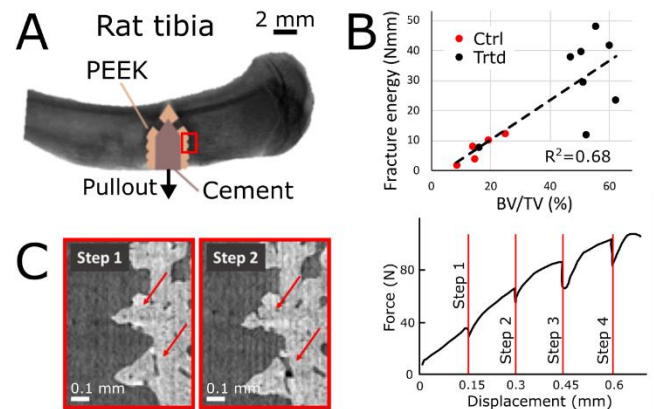


Fig. 1 A) Setup for *in situ* pullouts. B) Correlation between BV/TV and fracture energy for the Ctrl and Trtd groups. C) SR-CT images of cracks forming during the pullout and the force-displacement curve of a treated specimen.

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.

Acknowledgements

We thank Assoc. Prof. Stephen Hall for his help with the *in situ* loading set-up. Funding by the Swedish Foundation for Strategic Research (SSF) within the Swedish national graduate school in neutron scattering (SwedNess, GSn15-0008). We acknowledge PSI, Switzerland for provision of SR beamtime at the TOMCAT beamline X02DA at SLS.

References

- [1] Le Cann S. et al., Front. Bioeng. Biotechnol. 6:1-10 2019
- [2] Raina D. B. et al., Acta Biomater. 96:619-630, 2019
- [3] Tudisco E. et al., SoftwareX 6:267-270, 2017