SYNCHROTRON RADIATION PHASE CT FOR THE INVESTIGATION OF NANO PROPERTIES IN FEMORAL HUMAN BONE

Boliang Yu (1), Loriane Weber (1,2), Alexandra Pacureanu(2), Remy Gauthier(3), Cecile Olivier(1,2), Max Langer(1,2), Helene Follet(4), David Mitton(3), Peter Cloetens(2), Françoise Peyrin (1,2)

1. Creatis, Inserm U1206, CNRS 5220,INSA Lyon, UCBL, 69621 Villeurbanne, France
2. ESRF, 38053 Grenoble Cedex, France;
3. Université de Lyon, Université Claude Bernard Lyon 1, IFSTTAR, Lyon,France;
4. Université de Lyon, Université Claude Bernard Lyon 1, INSERM UMR1033, Lyon, France

Introduction

The mechanisms of bone fragility in relation to diseases such as osteoporosis remain only partially understood. Extensive attention has been devoted to the osteocyte cell network, which plays a central role in bone remodeling, but for which observation remains challenging. To assess bone nano-structure, we propose to use a new 3D X-ray phase nano-CT setup developed at the ESRF (European Synchrotron Radiation Facility) in Grenoble, which targets to reach isotropic spatial resolution up to 20 nm. Images of cortical bone samples with isotropic voxel size of 120nm, 50nm and 30nm are presented.

Methods

Transverse cross-sections were cut from mid-diaphysis in femurs from women (50 to 95 years old). Then, small cortical bone samples (0.4x0.4x3 mm^3) were prepared using a high precision low-speed circular saw. Imaging was performed on a new magnified X-ray phase nano-CT device developed at beamline ID16A at ESRF. The sample is placed on a sample stage in vacuum and illuminated with a pink beam extracted from synchrotron radiation at 17 or 33 keV.

Image acquisition consists in recording four CT data sets at different sample positions between the X-ray source focus and detector. The 3D images were reconstructed in two steps: 1) phase retrieval, to recover the phase shift at each rotation angle, 2) Filtered Back Projection tomographic reconstruction. They provided maps of refractive index decrement δ. Imaging was performed for 9 samples at 120 nm, and at either 50 or 30 nm. For each 3D image $(2048)^3$, we computed central slices and Maximum Intensity Projections (MIP) in each direction. The quantitative analysis of osteocyte lacunae was performed on images at 120nm.

Results

Acquisition time for a complete dataset (i.e. with 4 focus-to-sample distances) was approximately 4 hours. The 3D images were successfully reconstructed. Figure 1 illustrates slices (a)-(c) and MIP images (b)-(d) respectively at 120nm (top line) and 30nm (bottom line). The osteocyte system can clearly be observed at 120nm while at higher spatial resolution (30nm in Figure 1c), the texture of collagen fibers is visible. The 3D phase tomography images were converted to equivalent mass density maps, thus providing information on bone mineralization.

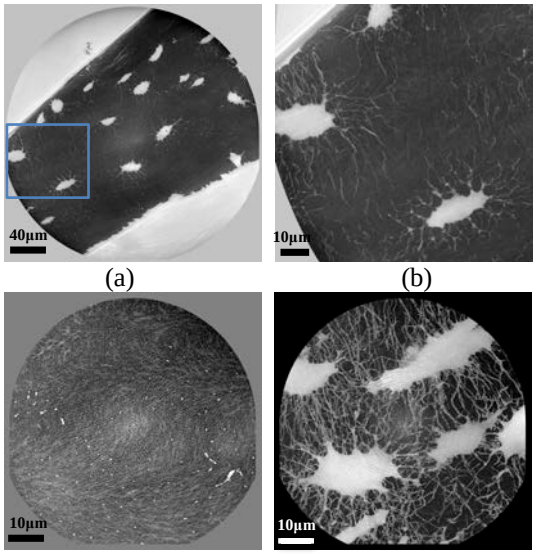

Figure 1: cortical bone images obtained with X-ray phase nano-CT at 120 nm (top line) and 30 nm (bottom line). (a)-(c): selected slices (b)-(d) MIP images

Discussion

The data was acquired on a new phase nano-CT setup optimized for nanoscale imaging. Despite the high radiation dose, the samples appeared to remain stable during the scans. The alignment of the recorded images at different magnifications was found to be crucial for phase retrieval. In the future, our goal is to extract quantitative parameters from these phase CT images and to correlate them with experimental biomechanical tests performed on neighboring regions in the bone.

References

1. Bonewald LF, JBMR, 26:229-238, 2011.
2. Pacureanu et al, MedPhys, 29:2229-2238, 2012.
3. Langer et al, PlosOne, 7:e35691, 2012.

Acknowledgements

This work was supported by the ANR grant ANR-14-CE35-0030-01 and by the Région Rhône-Alpes. It was also done in the framework of LabEx PRIMES (ANR-11-LABX-006"). We thank the ESRF for support through the LTP MD830.