Assessment of the lacuno-canalicular network in human bone from magnified phase nano-CT images

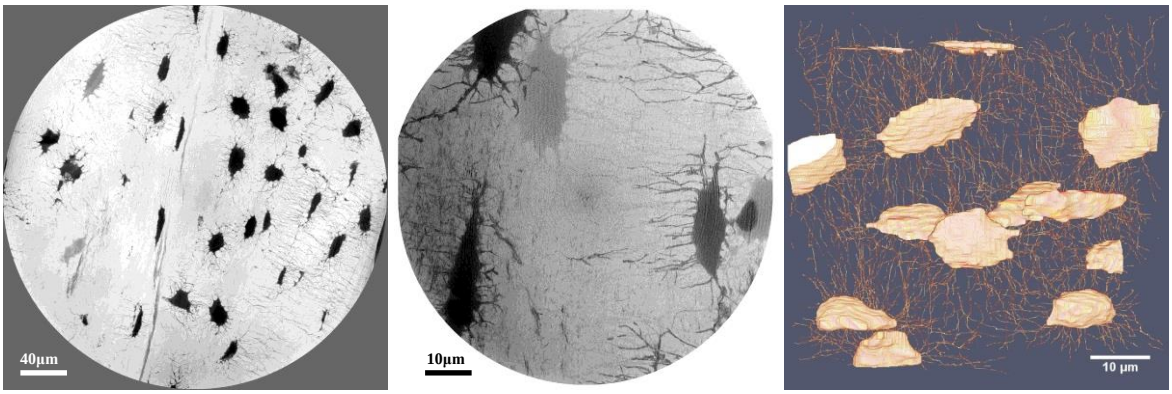
Boliang Yu[1], Max Langer[1], Alexandra Pacureanu[2], Cécile Olivier[1, 2], Pierre-Jean Gouttenoire[1, 2], Peter Cloetens[2], Françoise Peyrin[1, 2]

1 Univ Lyon, INSA Lyon, Université Claude Bernard Lyon 1, CNRS UMR 5220, Inserm U1206, Creatis, 69621 Lyon, France;
2 ESRF, 38043 Grenoble Cedex, France.

ABSTRACT

The osteocyte system, which plays a major role in the triggering of bone remodeling, has recently attracted increasing attentions but its properties in association to bone fragility are still unclear. It is residing the lacuno-canalicular network (LCN) which appears as a complex mesh where lacunae serve as nodes connected with each other by many small channels (canaliculi). Since it is deeply embedded inside bone tissue, the 3D analysis of the LCN at high spatial resolution is still challenging, although a number of 3D imaging techniques have recently been proposed. Here, we propose to use X-ray magnified phase nano-CT (nCT) to extract quantitative information about the LCN in human bone. Small samples were cut from cross sections of the mid-diaphysis of the left femur of 4 women cadavers (ages 56 - 95 years old). Imaging experiments were performed at the beamline ID16A of the European Synchrotron Radiation Facility (ESRF), Grenoble. For each samples, phase contrast CT scans were acquired at four different propagation distances, at voxels sizes of 120 and 30nm. After phase retrieval and tomographic reconstruction, the lacunae and canaliculi were segmented from the volumes at 120nm, by the hysteresis thresholding algorithm and a dedicated 3D minimal path method respectively. Due to the large nCT data sets (32 GB/ $(2048)^3$ image), the computations for the canaliculi segmentation were parallelized on a cluster of computers. Quantitative parameters could then be calculated from the binary images. Table 1 presents lacunae parameters including the lacuna porosity, density as well as morphological parameters. The development of image analysis methods for the images at 30nm is in progress. This work is expected to bring new characteristics of the LCN in three dimensions at the nano scale which will be correlated to biomechanical parameters measured on the same subjects.

Keywords: X-ray nano-CT, bone imaging, osteocyte system, lacuane



(a) (b) (c)

Figure 1: X-ray phase nano-CT images. (a) Minimum Intensity Projections (MIPs) of 100 slices in the middle of the reconstructed volume at 120 nm; (b) MIPs of the reconstructed volume at 30 nm; (c) Segmentation of LCN at 120 nm

Table 1: Quantification of lacunae at 120 nm

Sample ID	Lc.N	BV (μm^3)	Lc.TV/BV (%)	Lc.N/BV (mm^{-3})	Lc.V (μm^3)	Lc.S (μm^2)	Lc.L1 (µm)	Lc.L2 (µm)	Lc.L3 (µm)
#1	196	8.72×10^6	0.86%	22477	382.38	366.56	19.43	9.22	4.61
#2	294	11.55×10^6	0.88%	25456	346.42	354.07	17.17	10.28	4.35
#3	222	11.07×10^6	0.73%	20056	366.06	351.33	18.02	9.45	4.79
#4	340	11.39×10^6	0.94%	29845	315.83	315.80	17.27	8.48	4.84

Lc.N - number of lacunae
BV - bone volume in μm^3
Lc.TV/BV - lacunar volume density %
Lc.N/BV - lacunar number density in μm^{-3}
Lc.V - average lacunae volume in μm^3
Lc.S - average lacunae surface area in μm^2
Lc.L1, Lc.L2 and Lc.L3 – average length, width and depth of lacunae