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Rémy Gauthier, Hélène Follet, Cécile Olivier, David Mitton, Françoise Peyrin

3D ANALYSIS OF THE OSTEONAL TISSUE IN HUMAN CORTICAL BONE

Rémy Gauthier (1,2), Hélène Follet (3), Cécile Olivier (2), David Mitton (1) and Françoise Peyrin (2)

1.Univ Lyon, Université Claude Bernard Lyon 1, IFSTTAR, LBMC UMR_T9406, F69622, Lyon, France; 2.Univ Lyon, CNRS UMR 5220, Inserm U1206, INSA Lyon, Université Claude Bernard Lyon 1, Creatis, F69621 Villeurbanne Cedex, France; 3.Univ Lyon, Université Claude Bernard Lyon 1, INSERM, LYOS UMR1033, F69008, Lyon, France.

Introduction

The difficulty to predict human cortical bone fragility is partly due to its complex multiscale architecture[1]. In particular, osteons, considered as bone structural units arise through the remodeling process that occurs at the canals surface, and are assumed to play a major role in bone mechanical properties[2].

If 2D data can be found in the literature, there is, however, still few 3D quantitative data regarding bone osteonal systems[3]. This lack of data can be explained by the difficulty to distinguish the osteon from the interstitial tissue using standard 3D imaging techniques. However, due to its sensitivity, synchrotron radiation micro-computed tomography (SR-µCT) in the quantitative phase retrieval mode was shown to be a good candidate to enhance the contrast of the osteons[4].

The objective of the current study was to investigate morphometric parameters of osteons in human cortical bone and their relation with osteocyte lacunae and micro-cracks using SR quantitative phase µCT.

Materials and Methods

Rectangular cortical bone samples were extracted and prepared from eight female donors radii (50 to 91 y.o.). The image acquisition was performed on beamline ID19 at the European Synchrotron Radiation Facility (ESRF, France) using a "pink beam" with an energy of 31 keV. The effective pixel size on the detector was 0.7 µm. Phase contrast was obtained by propagation with a sample-to-detector distance set to 40 mm and phase retrieval was performed using Paganin's method[5]. The final Volume Of Interest (VOI) was 1x1.4x1.4 mm^3.

The osteons were segmented manually using Avizo software (Thermal Fischer Scientific). The Haversian canals, osteocyte lacunae and micro-cracks were segmented automatically using a home-made previously described method[6].

The bone volume (BV) was considered as being the complementary of the Haversian canals volume. The osteons volume fraction (Ost.V/BV), lacunar density (Lc.N/BV) and micro-cracks volume fraction (µCr.V/BV) were computed both in the osteonal volume (Ost.V) and interstitial volume (Inter.V). A Wilcoxon test for paired samples was used to investigate for differences between properties in osteonal and interstitial volumes.

Results and discussion

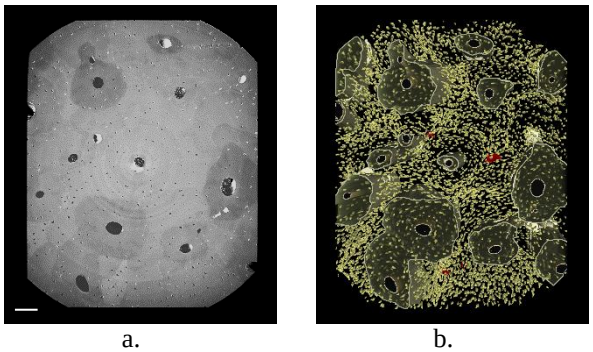
Table 1 reports the quantitative morphometric values and Figure 1 illustrates the original gray level volume and after the segmentation of the different structural features.

Table 1: Morphometric parameters (Average (SD)).

Morphometric parameters	Bone	Ost.V	Inter.V
Ost.V/BV (%)	43.2 (8.4)		
Lc.N/BV (mm^{-3})	19621* (2171)	20832 (2522)	18621 (1682)
µCr.V/BV (%)	8.3* (7.4)	2.4 (2.9)	12.2 (10.2)

*Significant difference between Ost.V and Inter.V ($p < 0.05$)

The difference of lacunar density between osteonal and interstitial tissue may reflect the remodeling process occurring within the osteons. The higher volume fraction of micro-cracks in the interstitial tissue suggests that they are formed in this older tissue, and that they cannot enter the osteons.



a. b.

Figure 1: 3D rendering of the VOI from a donor radius cortical bone (50 y.o.). a.: original phase contrast; b.: segmented volume (osteons surfaces: green, osteocytes lacunae: yellow, micro-cracks: red). Scale bar = 100 µm.

These novel 3D quantitative results regarding the osteocyte lacunae and micro-cracks properties in osteonal and interstitial tissue highlight the major role played by the osteons as structural units within human cortical bone.

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