Nanoscale characterization of hierarchical biological materials using synchrotron quantitative scanning-SAXS imaging

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The characterization of biological materials often proves challenging due to their high degree of structural hierarchy and their composite nature at the nanoscale. Bone is a typical example which presents an additional level of complexity because of the variety of morphologies encountered from the nanometer to the centimeter scale. This stems from the physiological processes associated with the synthesis, mechanical adaptation to external loads and self-healing. As a result, there is a growing consensus in the biomedical field over the necessity of multiscale approaches for the evaluation of the effects of bone pathologies. The molecular and supra-molecular levels, in particular, are currently receiving a lot of attention. At these scales, bone consists of complex arrangements of collagen microfibrils mineralized with calcium phosphate nanoparticles. Precisely how this nanoscale organization affects the mechanical properties of the higher hierarchical levels is still poorly understood.

In this paper, we will highlight the potential of quantitative scanning-SAXS imaging1,2,5 for such studies. This technique relies on scanning a sample with a monochromatic X-ray beam much smaller than the sample dimensions (typically 100 nm- 10 μm), and recording the scattered intensity in forward geometry. The images acquired at small scattering angles (SAXS) provide atomic to nanoscale resolution. They are reduced to scalar values by various algorithms based on the theory of SAXS and mapped as a function of scan coordinates to produce the final images. Using state-of-the-art X-ray optics and detectors with synchrotron sources, nanoscale fluctuations in density within a size range of ~1-100 nm can be mapped with very high spatial resolution over sample regions comparable to histology (cm2). This new method is therefore highly competitive and bridges the gap between TEM or AFM and high resolution microscopies.

Various results will be presented from fundamental, biomedical and archaeological studies to demonstrate the potential of this method. In particular, the size, organization and orientation of the mineral nanoparticules in bone will be described in various healthy and pathological/altered conditions.

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Fig. 1: qsSAXS Image of the particle size (nm) of a thin section (6 (H) x 10 (V) mm2 x 50 μm) iliac crest biopsy of a sheep model.