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Feedback Report

MD 293: A comprehensive study of the relationship between elastic stiffness and mineral structure in bone

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The goal of this proposal was to identify the structural determinants of the micro-mechanical properties of bone at the tissue level. It is well known that the remarkable biomechanical properties of bone, as many other biological systems, result from a complex hierarchical structural organization. Hence, the macroscopic behavior at the organ level is determined by factors including bone mass, volume, architecture and also by the ultrastructure of the tissue. The latter is currently receiving considerable attention in studies of bone pathologies such as osteoporosis. However, the structural origins of the mechanical properties at the tissue level remain poorly understood. This essentially stems from the heterogeneity of the tissue which consists of a patchwork of bone packets deposited at different growth stages. Furthermore, in mature bone, complex sequences of remodeling events occur, leading to a complicated microstructure where the presence of refined mesoscale architectures, such as osteons, can be observed. As a result, it is still not clear how the complex organization of the collagen fibrils within bone packets or the properties of the mineral nanoparticles affect the elastic properties of the tissue.

The main difficulty in addressing such questions is that characterization methods are required with nanometer scale resolution over fields of view comparable to the size of the structural units formed during remodeling (characteristic length ~ 100 μm). Most available techniques which provide nanoscale resolution, such as transmission electron microscopy (TEM) or atomic force microscopy (AFM), are therefore not suitable for such studies since they only provide limited fields of view. For this purpose, we therefore combined scanning small-angle X-ray scattering (sSAXS) imaging with synchrotron radiation microtomography (μCT) and 1 GHz-scanning acoustic microscopy (SAM). Thus, maps of the properties of the nanoparticles (e.g. size) and of the orientation of the microfibrils derived from the SAXS measurements were compared to the mineral density obtained by μCT over the same regions. Finally, the correlations between these parameters and the elastic properties derived from SAM-based acoustic impedance on the same samples were examined. In this way, we were able to provide, for the first time, experimental evidence of the strong correlation between elastic properties and the orientation of the mineralized collagen fibers, indicating that the fibril orientation is the main determinant of the elastic properties of the osteons while the size of the mineral nanoparticles only play a minor role. This is an important result that improves our current understanding of the biomechanical behavior of bone. A paper is currently in preparation which will be submitted to a high ranking journal. Our results have also been presented in several international conferences with very positive feedback from the biomechanical and structural communities.