A MULTIMODAL ANALYSIS OF CEMENT LINES IN HUMAN OSTEONAL BONE

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Cement lines (CLs) are thin layers separating secondary osteons from each other or from interstitial bone. Previous evidence suggests that CLs protect osteons by deflecting microcracks. However, their composition and structure still remain uncertain. In the present study, we characterize CLs mineral content and mechanical properties at the micrometer scale using cortical bone samples from 2 human femurs. We perform backscattered electron imaging, both quantitative (qBEI) and at higher resolution (hrBEI), to obtain 2D maps of mineral content and nanostructural features of 74 osteons. We manually segment CLs from their corresponding osteon, also considering concentric layers of bone (~1.1 µm in width) adjacent to the CLs. We compare the mineral content of CLs to the mineral content of the inside and outside neighboring layers of their corresponding osteon. We also measure the reduced modulus (E_r) and hardness across the CLs using nanoindentation (nIND) in 25 selected regions to correlate them with mineral content. At the micrometer scale, CLs appear 10 ± 3.5% more mineralized than their corresponding osteon. The CL mineral content is quite heterogeneous but has a stronger spatial correlation with the mineral content of the layers outside rather than inside the osteon ($p < 0.01$). This may suggest an interplay between the CLs mineralization and the mineral content of the surrounding bone, which is locally recycled to build the new osteon [Roschger, Acta Bio 2020]. As illustrated with a specific region in Fig. 1, we exploit indentation maps to compute the average E_r inside each CL, as well as within stiffer and more compliant lamellae (here 26.45 ± 1.31 GPa, 22.98 ± 2.71 GPa and 20.69 ± 2.05 GPa, respectively) by analyzing the corresponding post-nIND hrBEI image. Overall, we highlight a periodic alternation of stiffer and softer regions ($p < 0.01$) corresponding to lamellae of different fibers orientations. Additionally, CLs are stiffer and harder ($p < 0.01$) than their corresponding osteon. This mechanical contrast between CLs and lamellar regions may be one additional factor for hampering cracks entering the osteons. Recent findings that CLs have reduced nanoscale porosity in comparison to adjacent lamellar bone could explain the measured higher mineral content and stiffness [Tang, JBMR 2023]. Ongoing work focuses on the mineral properties of CLs measured with X-ray scattering as well as on the interplay between CLs and the osteocyte lacuno-canalicular network.