Human Bone as a Structural Material: Origins of its Fracture Resistance and Biological Degradation

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The hierarchical structure of human cortical bone evolves over multiple length-scales from its basic constituents of collagen and hydroxyapatite at the nanoscale to osteonal structures at near-millimeter dimensions, all of which provide the basis for its mechanical properties. To resist fracture, bone's toughness is derived intrinsically through plasticity (*e.g.*, fibrillar sliding) at structural-scales typically below a micron and extrinsically (*i.e.*, during crack growth) through mechanisms (*e.g.*, crack deflection/bridging) generated at larger structural-scales. Biological factors such as aging lead to a markedly increased fracture risk, which is often associated to a loss in bone mass (*bone quantity*). However, biologically-related structural changes can significantly degrade *bone quality*, again occurring at varying multiple length-scales. Using FTIR/UV-Raman spectroscopy and *in situ* small-/wide-angle x-ray scattering/diffraction to characterize phenomena at molecular to sub-micron scales and synchrotron x-ray computed tomography and *in situ* fracture-toughness measurements in the SEM to characterize effects at micron- to macro-scales, the mechanisms responsible for the diminished fracture resistance of human bone due to factors such as aging, irradiation and disease are examined.

(*below*) Hierarchical structure of human bone and the many mechanisms of toughening (both intrinsic and extrinsic) which are directly related to a specific structural scale.

(right) Scanning electron micrographs and synchrotron x-ray tomographs showing the change in crack paths in cortical bone following x-irradiation.