MECHANICS OF BONE TISSUE REVISITED FROM NANO TO MACRO

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In a biomechanical perspective, the clinically relevant concept of bone quality is essentially determined by the material properties of bone tissue. What are these material properties and how are they affected by growth, remodeling, aging, disease, treatment and healing? Despite significant advances of the field in the past decades, these questions have not been answered completely.
Bone tissue is a **hierarchical composite** including a mineral phase, a collageneous phase and water. Beyond these heteroclite molecular constituents, bone tissue exhibits three major levels of organisation that determine its macroscopic mechanical behaviour.
The first level of organisation, the **mineralized collagen fibril** represents the most challenging level from the experimental point of view. The arrangement and bonds of the few nanometer thick hydroxyapatite platelets with the cross-linked collagen fibrils appear to be the key to understand deformation and load transfer in this elementary unit. Damage necessarily initiates at this level and osteointegration depends on the resulting surface chemistry.
The **lamella** represents the second level of organisation and was mainly investigated by scanning nanoindentation. The rotated plywood configuration of the lamellae controls the orientation of the mineralized collagen fibrils and inhibits microcrack propagation. However, mechanical-morphological relationships are still missing at this level.
The third level is the **bone structural unit** (BSU) resulting from the bone remodeling process. These BSU exhibit heterogeneous mineralization, damage and microcrack densities. While single osteons have been previously tested in tension, compression and torsion, most studies interested in the influence of diet, pharmacological treatment or gene mutation on BSU mechanics were performed using nanoindentation.
The **compact and trabecular microstructures** constitute the macrosopic level. While poroviscoelasticity, damage and fracture of bone tissue have been the object of an impressive number of studies, it remains unclear how these properties are quantitatively affected by the lower levels of organisation. In a clinical perspective, material models of bone tissue are developed to compute the mechanical behaviour of whole organs that will hopefully contribute to improve prevention and treatment of osteoporosis and other bone diseases.

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