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Microscale Osmotic and Mechanical Properties of Cartilage

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Articular cartilage is a thin layer of tissue that exhibits time-dependent viscoelastic behavior. Its principal function is to facilitate the transmission of loads to the bone and to provide a smooth, lubricated surface for low friction articulation. Cartilage is unique in its ability to withstand high loads, without damage or degenerative change. It consists of a fluid and a solid phase. The principal component of the fluid phase is water, which contains ions (sodium, calcium, chloride, potassium, etc.). The solid phase is porous and permeable. The composition and hierarchical organization of cartilage extracellular matrix (ECM) defines the biomechanical properties of the tissue. The ECM consists of highly charged proteoglycan aggregates enmeshed in a network of collagen fibrils. The proteoglycan aggregates provide compressive resilience to the tissue through negative electrostatic repulsion forces. The contact force during joint loading increases the fluid pressure and causes the fluid to flow out of the ECM. When the compressive load is reduced, fluid flows back into the tissue. Because articular cartilage tends to stiffen with increased strain, its mechanical response cannot be described by a single Young's modulus.

We have developed an experimental approach based on combination of atomic force microscopy (AFM) and tissue micro-osmometry (TMO) for investigating the microscale mechanical and osmotic properties of articular cartilage. Since the non-linear elastic response cannot be resolved by the Hertz model using small and sharp atomic force microscope tips, we determined the microscale Young's modulus through a non-Hertzian approach with a spherical tip. The elastic modulus and osmotic modulus maps constructed for cartilage layers reveal the spatial variation of structural inhomogeneities. Measurements made on a two-year old bovine cartilage sample will be presented.