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Cartilage Multiscale Structure and Biomechanical Properties

Ferenc Horkay

Section on Tissue Biophysics and Biomimetics, Program in Pediatric Imaging and Tissue Sciences, Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health

Cartilage is a tough load bearing tissue that has many biological functions. It acts as a shock absorber. The increase in water content affects the compressive stiffness of cartilage by reducing its ability to bear load. Increased hydration and loss of stiffness are early indicators of irreversible tissue degeneration.

Knowledge of the swelling behavior of cartilage is essential to understand its biological function. Cartilage swelling is governed by the thermodynamic interactions between its constituents. The main macromolecular components of cartilage extracellular matrix are collagen (10-30% of the wet weight of healthy tissue), proteoglycans (4-10%), and water containing dissolved electrolytes (60-85%). Proteoglycans (PGs) consist of a protein core to which linear polysaccharide chains (glycosaminoglycans) are attached through covalent bonds. The negatively charged PGs generate an osmotic swelling pressure within the tissue, which is balanced by the collagen network. In cartilage the major PG is aggrecan, which binds to hyaluronic acid and forms large aggregates. In the bottlebrush-shaped aggrecan molecule chondroitin sulfate and keratan sulfate chains are tethered to a core protein. Relatively little is known how the molecular and supramolecular organization of PG assemblies influences the macroscopic properties of the tissue, such as its compressive resistance and load bearing capacity. To better understand the function of cartilage at the tissue level, we studied its osmotic and mechanical properties using complementary macroscopic and microscopic techniques. We developed a multiscale experimental approach to determine the physical properties of the main macromolecular components of cartilage extracellular matrix by combining macroscopic techniques (osmotic pressure measurements and mechanical tests) with scattering methods (light scattering, small-angle neutron and X-ray scattering) that probe the static structure at higher resolution. The dynamic response of proteoglycan assemblies is investigated by rheological measurements and dynamic light scattering.