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Morphology and biomechanics of articular cartilage

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Articular cartilage is a hypocellular, aneural, avascular, and alymphatic connective tissue. In adults, articular cartilage comprises a small (1–5%) population of chondrocytes and mostly (80–95%) extracellular matrix. About 60–80% of the ECM's wet weight consists of extracellular water, which is retained by the negatively charged proteoglycans. There is a strict relationship between cartilage composition and morphological organization and its biomechanical behavior. Water flows through the porous structure by matrix compaction, and the subsequent structural deformation increases with time under the constant compressive load until equilibrium is reached. This time-dependent behavior is described as viscoelastic. Moreover, the mechanical response to stresses differs depending on the direction of the loads applied, due to the inhomogeneous orientation of collagen fibers and other macromolecules.

Under compression, the matrix is compacted and pressure in the interstitium rises, forcing water and soluble ions out of the tissue. However, cartilage has very low permeability, which means that very high pressures are required to move water through the tissue. As a consequence, in vivo, fluid pressure accounts for a significant component of total load support, dissipating and minimizing the stresses—a phenomenon called "stress shielding of the solid matrix."

The collagen-proteoglycan matrix is also responsible for the flow-independent viscoelastic shear resistance of articular cartilage. In vivo, shear stresses are observed mostly during compression. In fact, a compression applied to an expandable tissue results in an expansion of the tissue itself, perpendicular to the direction of the load applied. Fortunately, cartilage compression results in stiffening of the tissue: the stiffer the matrix, the more energy is required to stretch the fibers. This leads to an increase in cartilage resistance to shear as compression is applied. Nevertheless a "pitfall" in this mechanism is created by the firm attachment of deep zone cartilage to the tidemark. Here, thick collagen fibers connect the deep zone to the calcified cartilage. In this area, the hard bony substrate prevents any expansion and energy dissipation and, during compression, shear forces attain their highest values. This explains why a hard, blunt impact may cause cartilage to be sheared off the bone, by the unbalanced peak stresses at the bone interface.

All these different biomechanical properties coexist during joint motion and they strongly interact with chondrocytes for cartilage matrix maintenance.

Key words

Articular cartilage, morphology, biochemistry, biomechanics