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Biophysical Modeling and Mechanobiology of Cartilaginous Tissues[1]

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Cartilaginous tissues (e.g., knee cartilage and intervertebral disc) are subjected to a wide range of mechanical loading associated with the daily physical activities. The development and maintenance of tissue structure and mechanical characteristics are tied directly to the effect of mechanical loading on the biology of cartilage cells and the extracellular matrix (ECM). Mechanical loadings produce complex physical-chemical environment changes around cartilage cells, including spatial-temporal variations of stress, strain, fluid flow, fluid pressure, osmotic pressure, fixed charge density, pH, electrical field, and solute transport within the ECM. These physicochemical signals across the ECM, which are difficult to be measured, can be quantitatively determined by using appropriate theoretical models for the mechano-electrochemical behaviors of cartilage. These models provide an essential framework for correlating the spatial-temporal distributions of physical stimuli surrounding cells with external loading at the tissue level. We introduce a multiphasic mechano-electrochemical model for cartilaginous tissues based on the general mixture theory. Correspondingly, the techniques are discussed for establishing constitutive relationships in the model for mechanical, electrical, and transport properties. In addition, the effect of physicochemical signals on cartilage cell homeostasis is demonstrated. The presented studies are important to the understanding of cartilage mechanobiology and shed light on how cartilage cells convert physical stimuli into cellular responses which can ultimately guide the maintenance of healthy cartilage and treatment of related disease.

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