

Swelling and Biomechanical Properties of Tissue-Engineering Cartilage

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Tissue behavior is governed to a large extent by composition and microstructure of the extracellular matrix. In cartilage, various biopolymers (glycosaminoglycans, collagen, hyaluronic acid, etc.) are integrated into a complex network that imparts the tissue with its low-friction characteristics and load-bearing capacity. The structure of collagen (predominantly type II collagen) gives it tensile strength and produces a tissue that is not only strong in tension but also resistant to compression. This is achieved by filling the collagen network with high molecular weight proteoglycans (primarily aggrecan), which draws water into the tissue and generates a large osmotic swelling pressure. This osmotic pressure places the collagen network under tension, and equilibrium is achieved when tension in the collagen network balances the swelling pressure of the proteoglycan-rich phase. We study the relationship between the main constituents of cartilage and its osmotic and mechanical properties using a variety of complementary experimental methods (tissue osmometry, atomic force microscopy, scattering techniques, and biochemical analysis). Cartilage was engineered from chondrocytes harvested from chick embryo sternum and cultured on poly(vinyl alcohol) hydrogel scaffolds. Osmotic swelling pressure at different stages of development was measured using a tissue micro-osmometer. Atomic force microscopy was used in tandem to map the local mechanical properties. The concentration of the main biopolymer components was determined by biochemical analysis. To study the contribution from individual components to the tissue's osmotic behavior, we performed osmotic swelling pressure and small angle neutron scattering measurements on solutions of the highly charged aggrecan of the hyaluronic acid and of collagen. The results, which shed light on the role played by each major constituent in cartilage biomechanics and osmotic properties, are discussed.