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Swelling of Fiber-Reinforced Soft Tissues is Affected by Fiber Orientation, Fiber Stiffness, and Lamella Structure

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Abstract

Native and engineered fiber-reinforced tissues are composites comprised of stiff collagen fibers embedded within an extrafibrillar matrix that is capable of swelling by absorbing water molecules. Tissue swelling is important for understanding stress distributions between collagen fibers and extrafibrillar matrix, as well as for understanding mechanisms of tissue failure. The swelling behavior of fiber-reinforced tissues in the musculoskeletal system has been largely attributed to the glycosaminoglycan content. Recent work demonstrated anisotropy in the swelling response of the annulus fibrosus in the intervertebral disc. It is well known that collagen fiber orientation affects elastic behavior, but the effect of collagen fiber network on tissue swelling behavior is not well understood. In this study, we developed three series of models to evaluate the effect of collagen fiber orientation, fiber network architecture (*i.e.*, single or multi-fiber families within a layer), and fiber stiffness on bulk tissue swelling, which was simulated by describing the extrafibrillar matrix as a triphasic material, as proposed by Lai *et al.* Model results were within one standard deviation of reported mean values for changes in tissue volume, width, and thickness under free swelling conditions. The predicted swelling response of single-fiber family structures was highly dependent on fiber orientation and the number of lamellae in the