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On Incorporating Osmotic Prestretch/Prestress in Image-Driven Finite Element Simulations of Cartilage

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Abstract

Medical imaging performed *in vivo* captures geometries under Donnan osmotic loading, even when the articulating joint is otherwise mechanically unloaded. Hence patient-specific finite element (FE) models constructed from such medical images of cartilage represent osmotically induced prestretched/prestressed states. When applying classical modeling approaches to patient-specific simulations of cartilage a theoretical inconsistency arises: the *in-vivo* imaged geometry (used to construct the model) is not an unloaded, stress-free reference configuration. Furthermore when fitting nonlinear constitutive models that include osmotic swelling (to obtain material parameters), if one assumes that experimental data–generated from osmotically loaded cartilage–begin from a stress-free reference configuration the fitted stress-stretch relationship (parameters) obtained will actually describe a different behavior. In this study we: (1) establish a practical computational method to include osmotically induced prestretch/prestress in image-driven simulations of cartilage; and (2) investigate the influence of considering the prestretched/prestressed state both when fitting fiber-reinforced, biphasic constitutive models of cartilage that include osmotic swelling and when simulating cartilage responses. Our results highlight the importance of determining the prestretched/prestressed state within cartilage induced by osmotic loading in the imaged configuration prior to solving boundary value problems of interest. With our new constitutive model and modeling methods, we aim to improve the fidelity of FE-based, patient-specific biomechanical simulations of joints and cartilage. Improved simulations can provide medical researchers with new information often unavailable in a clinical set-

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