Modeling some inelastic properties of collagen-rich biological tissues

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ABSTRACT

Collagen is the most abundant protein in mammals and equips soft biological tissues with stiffness, strength and fracture toughness. The abnormal alteration and degradation of collagen is involved in a large number of Extra Cellular Matrix (ECM) disorders. Consequently, modeling the load-carrying mechanisms of collagen may not only further contribute to our understanding of soft biological tissues biomechanics, but could also help to better understand collagen-related tissue disorders.

This work proposes a finite-strain constitutive model that considers the recruitment and sliding of collagen fibrils as the key factor in determining the characteristics of soft tissue biomechanics at higher load levels. Similar to other published models, our model employs Probability Distribution Functions (PDFs) to express the progressive recruitment and subsequent sliding of collagen fibrils. The kinematic description follows the multiplicative decomposition of the deformation gradient, and the constitutive description is partly based on earlier work [4, 1]. Although very simplistic, the model accounts for the sliding of the adjacent collagen fibrils and thus the translation of mutually interconnected proteoglycans cross-linking bridges, by virtue at a non-linear (hardening) model at the fibril level. Finally, in order to account for the dispersed alignment of collagen fibers observed in soft tissues,, we apply the general theory of fibrous connective tissue [3]. The integration over the unit sphere is carried out by t-designs [2], and the model has been implemented into the Finite Element (FE) package FEAP (University of California at Berkley).

The stress-stretch properties predicted for a single collagen fiber (MATLAB, The MathWorks, Inc.) were used to explore parameter sensitivity, to verify the FE implementation and to test the plausibility of the physical assumptions made in our model. Finally, the tearing apart of an Achilles tendon segment demonstrated the organ-level application of the proposed constitutive model and yielded good quantitative and qualitative agreement with data observed from in-vitro experimental testing.

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