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A computational framework for biomaterials containing three-dimensional random fiber networks

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ABSTRACT

Understanding the structure-function relationship of biomaterials can provide insights into different diseases and advance numerous biomedical applications. In this talk, I present a finite element-based computational framework to model biomaterials containing a three-dimensional fiber network at the microscopic scale. The fiber network is synthetically generated by a random walk algorithm, which uses several random variables to control the fiber network topology such as fiber orientations and tortuosity. The geometric information of the generated fiber network is stored in an array-like data structure and incorporated into the nonlinear finite element formulation. The proposed computational framework adopts the affine fiber kinematics, based on which the fiber deformation can be expressed by the nodal displacement and the finite element interpolation functions using the isoparametric relationship. A variational approach is developed to linearize the total strain energy function and derive the nodal force residual and the stiffness matrix required by the finite element procedure. Four numerical examples are provided to demonstrate the capabilities of the proposed computational framework, including a numerical investigation about the relationship between the proposed method and a class of anisotropic material models, a set of synthetic examples to explore the influence of fiber locations on material local and global responses, a thorough mesh-sensitivity analysis about the impact of mesh size on various numerical results, and a detailed case study about the influence of material structures on the performance of eggshell-membrane-hydrogel composites. The proposed computational framework provides an efficient approach to investigate the structure-function relationship for biomaterials that follow the affine fiber kinematics.