MECHANICS OF THE FINITE DEFORMATION BEHAVIOR OF BIOMACROMOLECULAR NETWORKS

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The force-extension behavior of many biomacromolecules is known to exhibit a characteristic repeating pattern of a nonlinear rise in force with imposed displacement to a peak, followed by a significant force drop upon reaching the peak (a "saw-tooth" pattern) due to stretch-induced unfolding of modules along the molecular chain. This behavior is speculated to play a governing role in the function of biological materials and structure. In this paper, models for the mechanical behavior of single modular macromolecules and networks of such macromolecules are developed enabling understanding of the manner in which this characteristic single molecule behavior is translated to the behavior of molecular strands, membranes, and solids. Single molecule force-extension behavior is modeled using the Freely-Jointed Chain and Worm-Like Chain models of statistical mechanics together with a new unfolding criterion based on the orientation distribution of folded modules. The single molecule behavior is then used within a continuum mechanics framework to construct constitutive models of the finite deformation stress-strain behavior of two- and three-dimensional networks of modular biomacromolecules. The proposed planar network model has applicability to biological membrane skeletons and the three-dimensional network model emulates cytoskeletal networks and solid biological tissues containing modular macromolecules. Simulation of the multiaxial stress-strain behavior of these networks illustrates the macroscopic membrane and solid stretching conditions which activate unfolding in these microstructures. The models simultaneously track the evolution in underlying microstructural features with different macroscopic stretching conditions, including the evolution in molecular orientation and the number of folded and unfolded modules. Specific examples of the applicability of such an unusual mechanical behavior in natural materials and biological materials will be discussed, where the load mitigation, dissipative and self-healing aspects of this behavior are highlighted.