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Nonlinear Elasticity in Biological Gels

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The mechanical properties of soft biological tissues are essential to their physiologic function and cannot easily be duplicated by synthetic materials. Unlike simple polymer gels, many biological materials including blood vessels, mesentery tissue, lung parenchyma, cornea and blood clots, stiffen as they are deformed, or strained. Stiffening under deformation allows tissues to be compliant at small strains and strengthen at larger deformations that could threaten tissue integrity. The molecular structures and design principles responsible for this non-linear elasticity are unknown. I will outline a molecular theory that accounts for strain-stiffening in a range of molecularly distinct gels formed from cytoskeletal and extracellular proteins and reveals universal stress-strain relations at low to intermediate strains. The input to this theory is the force-extension curve for individual semi- flexible filaments and the assumptions that networks composed of them are isotropic and that their elastic response is affine. The theory shows that systems of filamentous proteins arranged in an open crosslinked meshwork invariably stiffen at low strains without requiring a specific architecture or multiple elements with different intrinsic stiffness.