

Buckling soft tensegrities: Fickle elasticity and configurational switching in living cells

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Abstract:

Tensegrity structures are special architectures made by floating compressed struts kept together by a continuous system of tensioned cables. Their existence in a mechanically stable form is decided by the possibility of finding geometrical configurations such that pre-stressed tendons and bars can ensure self-equilibrium of the forces transmitted through the elastic network, the overall stiffness of which finally depends on both the rigidity of the compressed elements and the cables' pre-stress. The multiplicity of shapes that tensegrity structures can assume and their intrinsic capability to be deployable and assembled, so storing (and releasing) elastic energy, have motivated their success as paradigm –pioneeringly proposed three decades ago by the intuition of Donald E. Ingber–to explain some underlying mechanisms regulating dynamics of living cells. The interlaced structure of the cell cytoskeleton, constituted by actin microfilaments, intermediate filaments and microtubules which continuously change their spatial organization and pre-stresses through polymerization/depolymerization processes, seems in fact to steer migration, adhesion and cell division by obeying the tensegrity construct. Even though rough calculations lead to estimate discrepancies of less than one order of magnitude when comparing axial stiffness of actin filaments (cables) and microtubules (struts) and recent works have shown bent microtubules among stretched filaments, no one has yet tried to remove the standard hypothesis of rigid struts in tensegrity structures when used to idealize the cell cytoskeleton mechanical response. With reference to the 30-element tensegrity cell paradigm, we thus introduce both compressibility and bendability of the struts and accordingly rewrite the theory to simultaneously take into account geometrical non-linearity (i.e. large deformations) and hyper-elasticity of both tendons and bars, so abandoning the classical linear stress-strain constitutive assumptions. By relaxing the hypothesis of rigidity of the struts, we demonstrate that some quantitative confirmations and many related extreme and somehow counter-intuitive mechanical behaviors actually exploited by cells for storing/releasing energy, resisting to applied loads and deforming by modulating their overall elasticity and shape through pre-stress changes and instability-guided configurational switching, can be all theoretically found. It is felt that the proposed new soft -strut tensegrity model could pave the way for a wider use of engineering models in cell mechanobiology and in designing bio-inspired materials and soft robots