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Emergent multiscale mechanics of living cells

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Abstract:
A hallmark of active biological materials, such as living cells, is their emergent mechanical properties exhibiting a mixture of fluid- and solid-like behaviors across multiple spatial and temporal scales. Because of their structure complexities, living cells exhibit a rich array of viscoelastic behaviors that have been probed by various experimental techniques. Yet, a comprehensive, integrated model of cell mechanics has not been achieved. For example, Young's modulus E of living cells obtained from different specimens and using experimental techniques under different sampling conditions and at different temporal and spatial scales varies by three orders of magnitude (0.1–100 kPa). The theoretical models for calculating E are often oversimplified with assumptions that can hardly accommodate the actual measurement geometry and complex material parameters of living cells. A unified theory that can explain the viscoelastic properties of living cells across different scales remains lacking. In this talk, I will present combined atomic-force-microscopy (AFM) measurements of stress relaxation and indentation force for 10 cell types ranging from epithelial, muscle, and neuronal cells to blood and stem cells, from which we obtain a unified quantitative description of the compressive modulus E(t) of individual living cells [1]. The cell modulus E(t) is found to have an initial exponential decay at short times t followed by a long-time power-law decay together with a persistent modulus. The three components of E(t) at different timescales thus provide a digital spectrum of mechanical readouts that are closely linked to the hierarchical structure and active stress of living cells. This work thus provides a reliable experimental framework that can be utilized to characterize the mechanical state of living cells and investigate their physiological functions and diseased states.

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[1] D.-S. Guan, Y.-S. Shen, R. Zhang, P.-B. Huang, P.-Y. Lai, and P. Tong, Unified description of compressive modulus revealing multiscale mechanics of living cells, Phys. Rev. Research. 3, 043166 (2021).