(Keynote) Wrinkling and folding dynamics of epithelial shells at multiple scales

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Abstract

Numerous natural and engineered structures are shaped as thin curved shells. When subjected to excessive compressive loading, these shells undergo buckling instabilities that result in wrinkling patterns. Epithelial tissues lining internal and external surfaces of the body are a class of thin shells that displays three distinctive mechanical features: they are viscoelastic over the time scales of physiological loading, they carry an active surface tension, and their stress-bearing elements are distributed across scales. Buckling of epithelial shells has been widely implicated in morphogenesis and patterning during development. However, how the distinctive mechanical properties of the epithelium enable buckling and how they control the subsequent morphological patterns is not understood. Here we establish the multiscale buckling dynamics of epithelial shells as a function of their mechanical and geometrical determinants and over several orders of magnitude in time and space. We developed an experimental system that allows us to sculpt epithelial shells and subject them to controlled deflation. By combining this system with a 3D computational model of the epithelium, we demonstrate a phase diagram showing that buckling is promoted by rapid deflation rates relative to a characteristic viscoelastic time of the system and is impaired by active surface tension. We show, further, that the tissue develops wrinkling patterns with different degrees of symmetry that depend on its size and shape. Strikingly, we find that epithelial buckling is a multiscale phenomenon involving long-lived supracellular folds but also short-lived subcellular wrinkles in the actin cortex. Informed by a 3D computational model, we harness the active viscoelastic behavior of the cell cortex to pattern epithelial folds of predictive geometry by rationally directed buckling. Our study shows that epithelial tissues can be understood as hierarchical materials with mechanical instabilities that can be harnessed to engineer morphogenetic events.

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