Theoretical and computational framework for upscaling active gels models of the actin cortex to epithelial mechanics, rheology and 3D shaping

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Epithelial monolayers perform a variety of mechanical functions, which include maintaining a cohesive barrier or developing 3D shapes, while undergoing stretches over a wide range of magnitudes and loading rates. To perform these functions, they rely on a hierarchical organization, which spans molecules, cytoskeletal networks, adhesion complexes and junctional networks up to the tissue scale. While the molecular understanding and ability to manipulate cytoskeletal components within cells is rapidly increasing, how these components integrate to control tissue mechanics is far less understood, partly due to the disconnect between theoretical models of subcellular dynamics and those at a tissue scale. To fill this gap, we propose a formalism bridging active-gel models of the actomyosin cortex and 3D vertex-like models at a tissue scale. We show that this unified framework recapitulates a number of seemingly disconnected epithelial time-dependent phenomenologies, including stress relaxation following stretch/unstretch manoeuvres, active flattening after buckling, pulsatile non-affine contractions, curling, or active superelasticity. We further apply the proposed modelling framework to understand and predict the mechanics and reshaping of 3D epithelia in the context of epithelial domes. More specifically, we examine the effect of size, shape and deformation rate on the mechanics of pressurized cell monolayers. We show how the active viscoelasticity of the actomyosin cortex enables the directed folding of rapidly deflating domes into pre-defined buckling patterns.
Overall, the proposed framework systematically connects subcellular cortical dynamics and tissue mechanics, and ties a variety of epithelial phenomenologies to a common subcellular origin.