A multiplicative decomposition for the folding of active viscoelastic tissue

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Abstract

During morphogenesis, the process by which organisms acquire their shape, tissues can fold, thus exhibiting active internal stresses due to molecular motors such as myosin. The fruit fly (*Drosophila Melanogaster*) embryo, notably due to its relative simplicity, short generation time, transparency allowing imaging and since it allows the use of the most advanced genetic tools, is a model system for tissue folding. It forms a nearly ellipsoidal single layer of _˜1000 cells surrounding a viscous compressible yolk where a furrow appears due to a localised increase of myosin activity. Myosin puts under tension the actin cytoskeleton, which surrounds each cell.
This cell monolayer can be modelled as two concentric closed shells, formed by the continuum of actin at the outer apical surface and at the inner basal surface of the epithelium. These two shells are in mechanical interaction, notably through the lateral actin cytoskeleton. We have previously shown that the initiation of this folding corresponds to the purely elastic buckling of the outer surface only of this epithelium under anisotropic tension (1). However, the dynamics of the subsequent flow during which the tissue actually folds, happening on longer timescales, remains elusive. Biological tissues undergoing morphogenesis are known to exhibit rapid elastic stress relaxation and plastic-like flows, leading to a viscoelastic liquid rheology. The challenge is thus to combine this complex rheology, active internal stresses and shape changes.

The 3D dynamics of these viscoelastic active shells can be conveniently solved using a multiplicative decomposition of the deformation gradient, a technique that has been widely used in thermoelasticity, elastoplasticity, as well as biomechanics, specifically for growth in tissues. As is the case for growth, the anelastic contribution of contractility can be understood as a dynamic prestrain (2). We derive an evolution equation for this anelastic deformation such as to recover an active gel model, namely the upper-convected Maxwell constitutive equation with an active term corresponding to this dynamic prestrain (3). Using this model, we address the dynamics of thin shells actuated by internal contractility.

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