Modeling of Epithelial Sheet Deformation Under External Force Applied By a Migrating Cell

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Abstract

Mechanics of living cells and tissues play a central role in many phenomena, from tissue shape formation (morphogenesis) to migration of cells within tissues. One prominent example is the epithelia - a sheet of cells tightly attached to one another. It provides a physical barrier to separate an organism's interior from the external environment and serves as a structural support for inner tissues, guiding their shape changes during development. In the Drosophila embryo, immune cells migrate along the inner (basal) side of an epithelial layer during their invasion into the germ-band and during this process exert an external force on the epithelial sheet to deform it. The mechanical properties of epithelial cells, in particular, surface tension and stiffness influence deformability of the sheet and, thus, the speed of migrating cells. Computational models can help to integrate experimental and theoretical knowledge and to dissect how the tissue mechanics emerges from mechanical properties of individual cells.

We constructed a finite-element model of an epithelial sheet in COMSOL Multiphysics® to examine its response to external forces (Fig.1). Each epithelial cell is modeled in 2D as an elastic shell (cell cortex) filled with incompressible fluid (cytoplasm). The cell cortex is divided into 3 domains with distinct material properties (outside apical, lateral and inner basal). Load is applied by an indentor on the basal side, simulating the force exerted by a migrating cell. Stationary force balance equations are solved using a Structural Mechanics module, analogous to the model of a hyperelastic seal.

Our model shows that similar shifts in tension of the different cortex domains distinctly affect sheet deformability, with the highest contribution from the basal domain. With the help of this model we analyze the experimentally measured epithelial deformations to deduce the mechanical properties of the epithelia that influence immune cell migration. This study contributes to understanding how a mutual mechanical balance is achieved in tissues to allow for robust mechanical events, such as cell translocation.

Figures used in the abstract

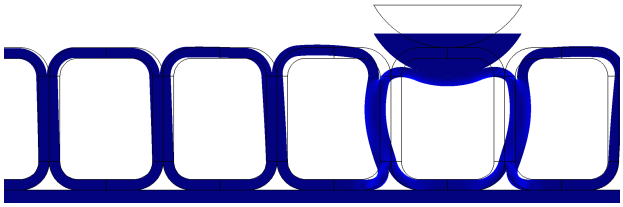

Figure 1: Epithelial sheet is deformed by a migrating cell from the basal side.