Vertex modeling of epithelial domes and tissue superelasticity

Sohan Kale[1], Ernest Latorre[1,2], Xavier Trepat[1,2] and Marino Arroyo[1,2]

[1]Universitat Politècnica de Catalunya-BarcelonaTech, Barcelona 08028, Spain and [2]Institute for Bioengineering of Catalonia, Barcelona 08028, Spain

Epithelial tissues are often curved into three dimensional shapes that enclose a pressurized lumen. Furthermore, during development and adult life these tissues can be highly stretched. However, the mechanics of epithelial monolayers under these conditions has not been quantitatively examined. Using soft micropatterned substrates we produce epithelial domes with controlled size and basal shape. By measuring 3D deformations of the substrate we obtain a direct measurement of epithelial tractions and luminal pressure. Tension in the freestanding epithelium is then mapped by combining measured luminal pressure and tissue curvature. Over time-scales of hours, we track tissue tension while epithelial domes reach nominal strains of 300%. Remarkably, we find that tissue tension reaches a plateau. Furthermore, despite the fact that the dome is subjected to uniform tension, the areal strain of individual cells can differ by more than one order of magnitude, with some superstretched cells reaching areal strains close to 1000%. To understand these observations, we develop a 3D vertex model [1,2]. We first note that a conventional 3D vertex model with constant junctional tension captures the tensional plateau under large stretches. However, when implemented computationally, this model does not replicate the cellular strain heterogeneity. We hypothesize that, as stretched cells increase their surface area by several fold, shortage of cytoskeletal components may lead to cell softening. We develop a model observing the limited amount of cortical material, which captures the tensional plateau and the cellular strain heterogeneity. According to this model, cells exhibit a non-convex multi-well energy landscape, and tissues accommodate stretch at constant tension by developing a mixture of cells in high- and low-strain phases, all of which are landmark features of superelasticity [3].

[1] S. Alt, P. Ganguly, and G. Salbreux. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 372(1720), 20150520 (2017).
[2] A. G. Fletcher, M. Osterfield, R. E. Baker, and S. Y. Shvartsman. Biophysical Journal, 106(11), 2291–2304 (2014).
[3] R. Abeyaratne and J. K. Knowles. Evolution of phase transitions: a continuum theory. Cambridge University Press, (2006).