

Surface tension determines tissue shape and growth kinetics

Abstract

The collective self-organization of cells into three-dimensional structures can give rise to emergent physical properties such as fluid behavior. Here, we demonstrate that tissues growing on curved surfaces develop shapes with outer boundaries of constant mean curvature, similar to the energy minimizing forms of liquids wetting a surface. The amount of tissue formed depends on the shape of the substrate, with more tissue being deposited on highly concave surfaces, indicating a mechano-biological feedback mechanism. Inhibiting cell-contractility further revealed that active cellular forces are essential for generating sufficient surface stresses for the liquid-like behavior and growth of the tissue. This suggests that the mechanical signaling between cells and their physical environment, along with the continuous reorganization of cells and matrix is a key principle for the emergence of tissue shape.

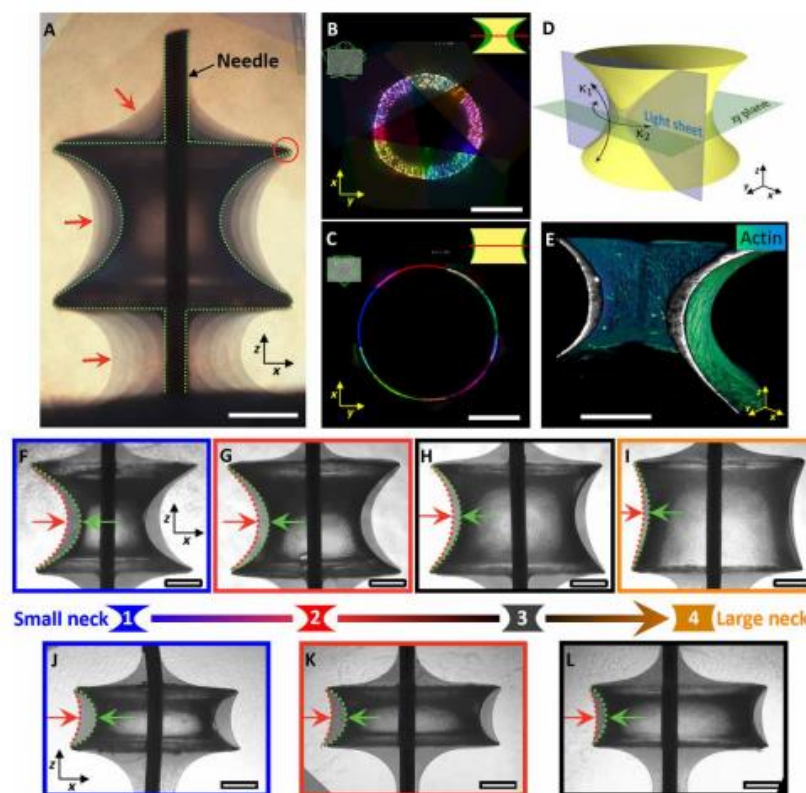


Fig. 1. CB geometry as a means to control 3D tissue growth. (A) Composition of phase-contrast images of tissues grown on a CB taken after 4, 7, 21, 32, 39, and 47 days. The tissue is pinned at the edges of the CB (red circle) and shows a moving contact line in between the scaffold and the Teflon holder, reminiscent of a liquid. Dashed line indicates the CB surface, and red arrows point toward the tissue-medium interface. Scale bar, 500 μm . (B and C) Radial slices at the neck for two different CB sizes with initial volumes of 1.1 μl (B) and 2.8 μl (C) obtained with LSFM from five different views. (D) Sample geometry and orientation of the light sheet. κ_1 and κ_2 are minimum and maximum principal curvatures. (E) 3D rendering of actin fibers on the sample shown in (F) color-coded according to fluorescence intensity. (F to I) Phase-contrast images of tissues grown on four different CB surfaces with initial volumes of 1.1 μl (F), 1.6 μl (G), 2.2 μl (H), and 2.8 μl (I). (J to L) CB surfaces with initial volumes of 1.1 μl (J), 1.3 μl (K), and 1.5 μl (L). Sample neck size increases from left to right. Green arrow indicates the interface of the initial shape, and red arrow indicates the position of the tissue-medium interface after 32 days. Scale bars, 400 μm .