Campàs group: Morphogenesis and self-organization of living matter

How do cells collectively create highly organized patterns? How are organs shaped? What rules do biological systems use to build such complex structures? Our goal is to understand how organization and patterns emerge in biological systems, and determine the role of mechanics in shaping biological structures. Solving these problems involves concepts from physics, multigenet systems, dynamical systems, mechanics, etc. We combine theory and experiments, as well as physics, biology, materials science and engineering, to obtain a global (or ‘systems’) understanding of these complex problems. Our current interests span several topics such as embryonic development, tissue growth, cell shape, and morphological variation.

**Tissue mechanics in morphogenesis**

How does a growing embryo form its shape? As the tissue grows, an interplay of forces in the living tissue and in the external environment gives rise to changes in organization and pattern formation. The ability to apply forces directly addresses how physical forces control the formation of living matter. To apply forces in vivo we use ferrofluid oil droplets to deform applying a magnetic field. (a) The magnetic field is generated by moving permanent magnets close to the sample. (b) We apply forces at the length scale of cells by deforming a ferrofluid droplet.

**Mechanical forces driving morphogenesis**

Taking advantage of oil micro-droplets as in vivo force transducers (Figures 1 and 2), we plan to measure the physical forces exerted by cells during blastula gastrulation. For example, by employing magnetic droplets we will describe the mechanical properties (tissue flexibility) of tissues undergoing regression (Figure 3). In addition, we plan to link the signals through YAP, a fundamental molecular mechanism, to specific mechanical stresses that characterize the early zebrafish embryo. YAP shuttles from the cytoplasm to the nucleus and we plan to describe the dynamics of its subcellular localization as a function of tissue tension (in the enveloping cell layer, the embryonic skin and compression in the deep cell layer) (Figure 4).

**How do cells get their shapes?**

Cells in many organisms are surrounded by a thin shell, the cell wall, that provides mechanical integrity to the cell and specifies its boundaries. We investigate how the mechanics and assembly of this wall control the shape of the cell. Our results show that despite large genetic differences across species, the interplay between mechanics and assembly governs the shape of the cell.

**Cellular packing in the early embryo**

This project seeks to understand how physical forces constrain and guide the arrangement of cells in early holoblastic embryos. Cells are modeled as particles with a mutual attractive potential to abstract mutual mechanical interactions between cells. Then the division of the cells is added and the resulting cell arrangements are characterized by their division to relaxation time scales and their division rules.

**Collective behavior of motor proteins**

The motion of single motors is well understood, but their collective behavior is not. We created biomimetic droplets to study the collective behavior of kinesin, a type of motor protein, in vitro. We expect these lipid-coated droplets to display different force-sharing properties than the rigid polylysine beads frequently used for motor studies.

**Cell migration**

From the fluking of birds to the schooling of fish, population level dynamics emerge from the action of individuals. However, there is still no complete theory describing how collective behavior in a population of cells can arise from local interactions within the tissue. Combining concepts from biology, central theory, and physics, in conjunction with in vitro and in vivo experimental observations, we are working to reveal the essential ingredients necessary for collective cell migration.

**Expected behavior**

- **Wall force**: Force per cell attached to the wall
- **Rigidity**: In the center of the disk, the wall force stems from the inherent flexibility of the cell membrane and can be explained using classical continuum theory.
- **Number of motors attached to the wall**: Motors are added to the cell membrane as the cell migrates.