M2 internship and PhD thesis

Can we measure the pressure within a tissue ?

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Context and motivation. Confluent biological tissues are active multicellular systems: cells consume energy (ATP) to generate motion, change shape and exert forces. Mechanical stresses are known to regulate cell proliferation, extrusion, differentiation and collective migration, so quantifying the pressure inside a tissue is a major biophysical question. Yet in out-of-equilibrium active systems the notion of pressure is subtle. Unlike in equilibrium, pressure is generally not a state function: the force exerted on a wall or probe can depend on how the active constituents interact with it (its shape, stiffness, compliance, and the nature of the contact). This implies that different pressure measurements (wall force, bulk stress, deformation of a probe) may give different answers for the same tissue. Biological cells make this problem harder than for synthetic active particles (self-propelled colloids, active Brownian particles). Cells deform, adapt and communicate; their interactions are intrinsically many-body rather than pairwise (a cell's mechanics depends on the whole polygon formed with its neighbors); and the direction of cell motility is coupled to cell geometry and/or to the orientation of neighboring cells. How these features affect the pressure exerted on a confining wall is largely unexplored.

Objectives. Combining numerical simulations and analytical calculations, the objectives of this internship/PhD project are:

1. Solve a minimal 1D model. Consider a chain of active cells confined by a deformable wall and compute analytically and numerically the force distribution on the wall and the mean pressure as functions of activity, persistence, cell stiffness and wall compliance. Analytical tools include Fokker–Planck and master equations, perturbative expansions in persistence or activity, and exact solutions where available. They will be compared with direct simulations.
2. Extend to a 2D cell monolayer. Use cell-based models with different couplings between motility, cell shape and neighbor orientation, and determine how these couplings modify the pressure and its dependence on the wall properties. Motility rules will include alignment of polarity with the cell's long axis, shape-dependent motility magnitude and neighbor alignment.
3. Establish a protocol for non-perturbative pressure measurement. Identify probe properties (stiffness, size, contact interaction) for which the measured pressure converges to a well-defined, probe-independent value, or characterize precisely how it depends on them. Propose practical guidelines for experiments.

Required skills: the candidate should have a strong inclination for theory (especially statistical physics and stochastic processes) and numerical simulations.

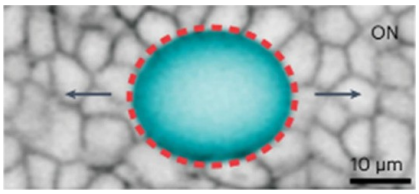


Figure 1: microdroplet used as a stress sensor, exerpt from Forigua, Campbell & Moraes, Curr. Op. in Biomed. Eng. (2025).