Physics of early Embryo Morphogenesis

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Abstract:

The mammalian preimplantation embryo is shaped via a series of cell divisions and cell re-arrangements, leading to the blastocyst, a stereotypical structure composed of an epithelial layer surrounding an inner mass of cells and a fluid-filled cavity. I will present our recent efforts to model the morphogenesis of the mammalian blastocyst combining 3D numerical simulations with concepts of soft-matter physics. In collaboration with biologists, we demonstrated that differential changes in cell surface tensions are sufficient to explain the process of compaction at 8-cell stage (1) and the formation of the inner-cell mass at the 8-to-16 cells transition (2). To simulate realistically these multicellular processes in 3D, I will introduce a new numerical platform based on triangular meshes, that we currently extend to tackle the development of other early embryos, which happens on much shorter timescales (3). I will finally introduce new results on the formation the blastocoel cavity, which begins with the growth of numerous lumens at each cell-cell interfaces in the 32-cell by osmotic pumping. We hypothesize that a single cavity forms by luminal fluid exchange, in a mechanism controlled by surface tension and analogous to the process of Ostwald ripening in foams. Theoretical predictions and preliminary experimental data indicate that differential tension between inner and outer cells may be sufficient to robustly determine the localization of the cavity, and to control, hence, symmetry breaking in early mammalian embryos.

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(2) Maître, J. L., Turlier, H., Illukkumbura, R., Eismann, B., Niwayama, R., Nédélec, F., & Hiiragi, T. Asymmetric division of contractile domains couples cell positioning and fate specification. Nature, 536, 344-348 (2016).
(3) Turlier, H.T., Audoly, B., Prost, J., Joanny, J.-F. Furrow constriction in animal cell cytokinesis. Biophys. J. 106, 114-123 (2014).

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