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The physics of cytokinesis in animal cells

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Cytokinesis is the process of physical cleavage during cell division. It proceeds by the ingression of an actin-myosin-enriched furrow at the equator of the cell. We identify the contractile actomyosin cortex as the main source of mechanical dissipation and active tension controlling cell shape dynamics. We derive a viscous active non-linear membrane theory of the cortex that explicitly includes the turnover of actin and where myosin activity is controlled in time and space by the cell. A Lagrangian implementation of this model allows us to calculate the full deformation of an initially spherical cell, when it is subject to a band of overactivity at the cell equator that mimics the RhoA signaling pattern. Our simulations reproduce the formation and ingression the actomyosin ring, with cell shapes and dynamics mirroring thoroughly the ones observed experimentally. This model predicts cytokinesis completion above a well-defined threshold of equatorial contractility excess, and simple scaling arguments unveil the key mechanism for this first-order transition: cytoplasmic incompressibility results in a competition between the furrow line tension and the cell poles surface tension. Our theory explains how cytokinesis duration may be independent on cell size in embryos and predicts a critical role for actin turnover on the rate and success of furrow constriction. We extend our theoretical approach to explore cell shape dynamics in other essential cellular processes, such as cell polarization or cell-cell adhesion.

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