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Chemoenvironmental modulators of single-cell fluidity and stiffness

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ABSTRACT

Biological cells can be classified as “active soft matter,” with mechanical characteristics modulated by external cues such as pharmaceutical dosage or fever temperature. Quantifying the effects of chemical and physical stimuli on a cell’s mechanical response informs models of living cells as complex materials. We discuss the mechanical behavior of single cells in terms of fluidity, or hysteresivity normalized to the extremes of an elastic solid or a viscous liquid. This parameter, which complements stiffness when describing whole-cell viscoelastic response, can be determined for a suspended cell within subsecond times. Questions remain, however, about the origin of fluidity as a conserved parameter across timescales, the physical interpretation of its magnitude, and its potential use for high-throughput sorting and separation of interesting cells by mechanical means. We have selected optical stretching, a noncontact tool that deforms cells in the suspended state via photonic pressure, to explore the linear power-law-rheology regime (1% strain, 1 s timescale) of single cells. Cells were probed for several seconds each by applying an oscillatory photonic stress, and machine vision was used to extract time-dependent elongation and phase lag from phase-contrast images. Our experiments employing various chemoenvironmental conditions – temperature, pharmacological agents, pH, and osmolarity – extend familiarity with suspended-cell mechanics in the context of both soft-matter physics and mechanical flow cytometry development. The strong influence of both osmotic volume changes and the cytoskeleton-disassembling drug latrunculin supports the interpretation of fluidity as a reciprocal friction within the actin cytoskeleton, with implications both for cytoskeletal models and for expectations when separating interesting subpopulations by mechanical means in the suspended state.