PHASE TRANSITIONS IN LIVING SYSTEMS: THE ROLE OF ADHESION IN TISSUE ARCHITECTURE

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The development of multicellular organisms orchestrates spatiotemporal changes where tissues undergo material transitions between fluid-like and solid-like behaviors, often described using phase transitions. In this context, the transition from a floppy to a rigid regime observed *in vivo* in zebrafish embryonic tissue has been interpreted through the lens of jamming and rigidity theory, where a critical cell fraction ϕ_c leads to the formation of a Giant Rigid Cluster (GRC) in which cells lose their capacity for independent motion. By applying new bioengineering strategies, we decoupled jamming from macroscopic mechanical response, creating tissues that exhibit solid- or fluid-like characteristics while being, respectively, jammed or unjammed. This counterintuitive phenomenon was explained by analytically identifying a second critical point in the relative surface tension α, beyond which a floppy motif of soft, adhesive cells becomes spontaneously rigid despite remaining below ϕ_c. Simulations confirm that this rigidity onset corresponds to a sharp increase in GRC size at the theoretically predicted α_c. Experiments further show that α reliably predicts the mechanical state of the tissue. These findings define a two-parameter phase diagram for embryonic tissues, structured around the critical values (ϕ_c, α_c). Through optogenetic and pharmacological manipulations, we navigated real tissues through this phase space, uncovering that distinct paths give rise to different morphological outcomes: mesenchymal, lumen-forming, or epithelial-like states. Our integrated theoretical and experimental approach shows how basic physical parameters such as packing and surface tension fundamentally influence tissue architecture, biomechanics, and developmental functions.

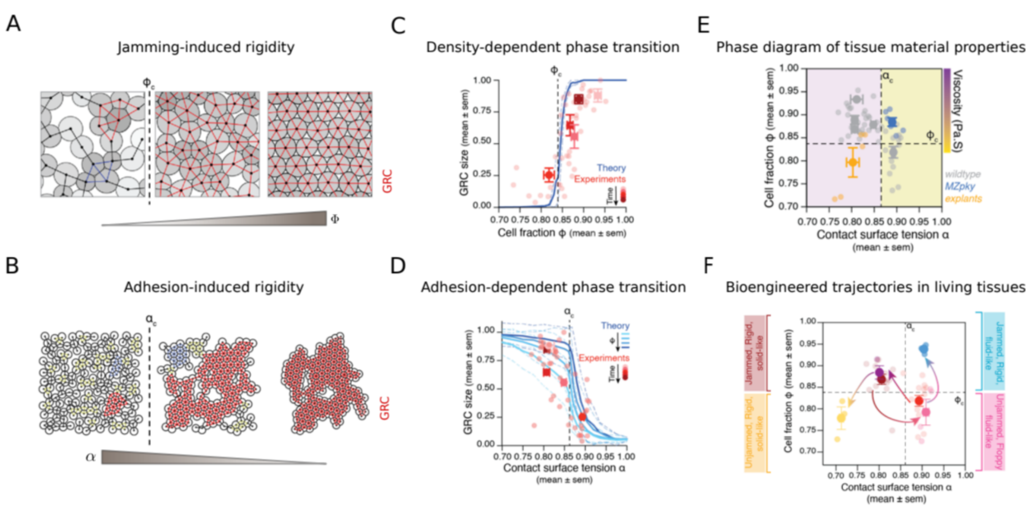

FIG. 1. Tissue rigidity phase transitions governed by cell packing and adhesion.

[1] L. Rustarazo-Calvo et al., BioRxiv (2025), `https://doi.org/10.1101/2025.03.18.644006`.

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