Advanced Simulations of Bio-Ink Extrusion Dynamics

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The flow of bio-inks outside the nozzle is a complex physical phenomenon. Swelling phenomena in the extrudate reduce printing resolution and induce internal stresses within the bio-ink. Additionally, material heterogeneity, such as that encountered in coaxial bioprinting, introduces a challenging interplay between elasticity and capillarity, making the final outcome difficult to control. This work aims to investigate the extrusion process in bioprinting by developing a simulation platform that solves the free-surface problem for typical viscoelastic responses of various bio-inks. The tracking of moving boundaries is managed with an Arbitrary Lagrangian-Eulerian (ALE) description and advanced mixed formulations, capable of handling localized and significant changes in surface curvature and abrupt stress distribution alterations. The proposed framework's validity is demonstrated through benchmark tests, and its applicability is explored by analyzing the complexity of multi-factorial design criteria in both classical and coaxial extrusion-bioprinting settings.