Holographic Biofabrication with Sound and Light

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Biofabrication seeks to combine biological building blocks - such as cells, biomaterials, and bioactive factors - with tuned biophysical cues. While conventional biofabrication treats the bioink as a homogeneous entity, remotely acting bioassembly methods open new possibilities by enabling the independent patterning and manipulation of living cells or microgels, decoupled from the light-driven polymerization process. Among these approaches, ultrasound has emerged as a powerful tool for advancing biofabrication, offering cytocompatibility, deep tissue penetration, and the ability to manipulate and stimulate cells through remotely generated acoustic radiation forces.

Our research focuses on creating complex acoustic fields using mode engineering or holographic principles to achieve precise spatial control over these force landscapes. By exploiting resonances in fluid droplets, we assembled biological cells to ring-shaped tissues in parallel, demonstrating a potential way of scaling the technique. In other works, we have shown how acoustic holograms enable the assembly of microparticles, microgels, and living cells into non-trivial, user-defined two- and three-dimensional patterns within a single exposure. The resulting ultrasound-driven cell compaction enables the use of bioinks containing up to 3 million cells per milliliter, producing constructs that reach cell densities exceeding 100 million cells per milliliter. These techniques complement established 3D biofabrication strategies and can be seamlessly integrated with other emerging modalities such as magnetic assembly or structured light. For instance, we employ microlithography to encapsulate ultrasound-assembled cell constructs within arbitrarily shaped hydrogel scaffolds, providing the mechanical support and microenvironmental cues for further tissue development. I will conclude by discussing the remaining challenges, including the standardization, scalability, and translational considerations crucial for the widespread adoption of ultrasound-based biofabrication in tissue engineering.