Development of Biocompatible Inks for 3D-Printed Drug Delivery Systems

BENNY LAB

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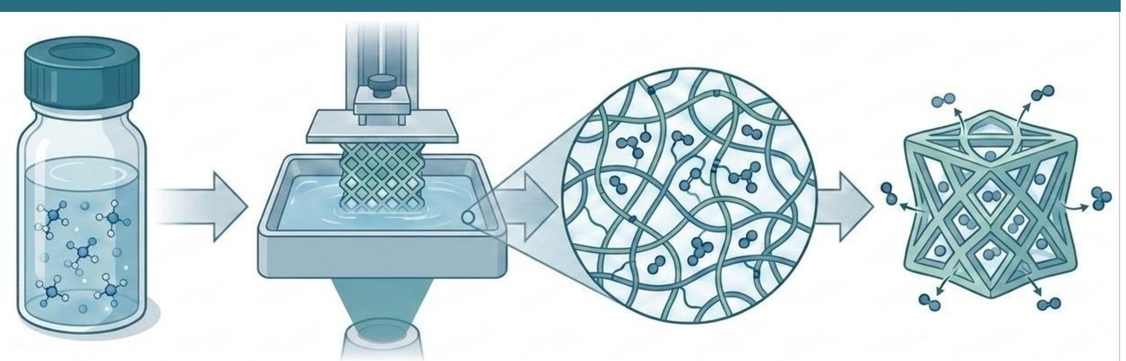
The Clinical Challenge

- **Standard methods often struggle with precise targeting, resulting in off-target tissue exposure.**
- **Drug delivery approaches tend to be "one size fits all", yet patient morphology and metabolism can vary significantly.**
- **Nowadays, 3D implants for biomedical uses typically support personalized structural matching without the incorporation of drugs.**

Research Goals

- **To formulate innovative, biocompatible 3D printing inks for printed drug delivery systems, allowing the synthesis of localized, custom-printed medical structures.**
- **To incorporate stimuli-responsive components that automatically release the drug in response to a physiological stimulus.**

How It Works



1. Formulating the Biocompatible Drug-Loaded Ink
A water-based polymer resin safely encapsulates therapeutic drugs while maintaining their chemical integrity.

2. High-Resolution DLP 3D Printing
Digital Light Processing cures layers with precision without damaging delicate pharmaceutical ingredients.

3. Tuning Release via Molecular Weight
Altering the polymer's molecular weight controls the network density and the rate of drug diffusion.

4. 4D Upgrading for Autonomous Release
Integrated reactive elements trigger a physical response to external stimuli, releasing the drug exactly when needed.

How It Looks

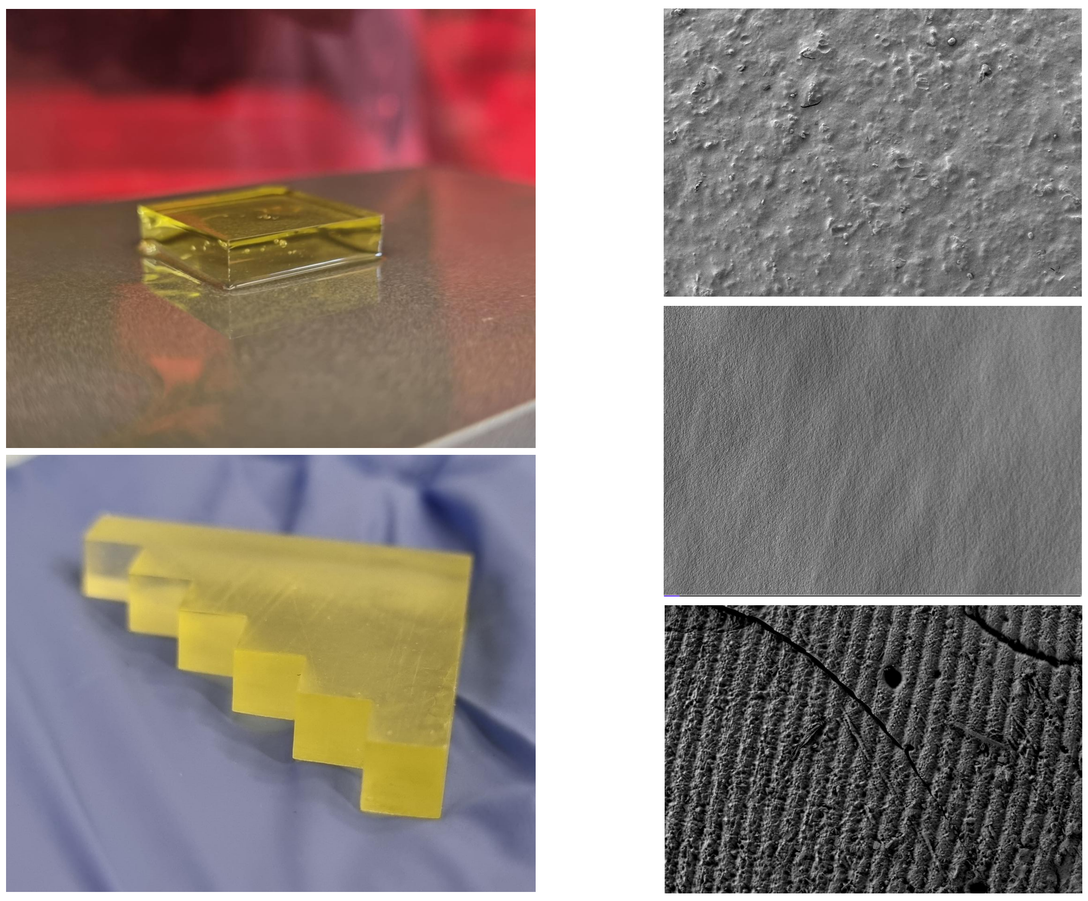


Figure 1. Structural Characterization of the Formulated Ink.
(A) DLP-printed, custom 3D-printed hydrogels demonstrate excellent shape retention and optical clarity.
(B) SEM Imaging showing the internal cross-linked polymer matrix forms a dense mesh.

Key Results: Drug Surrogate Release Test

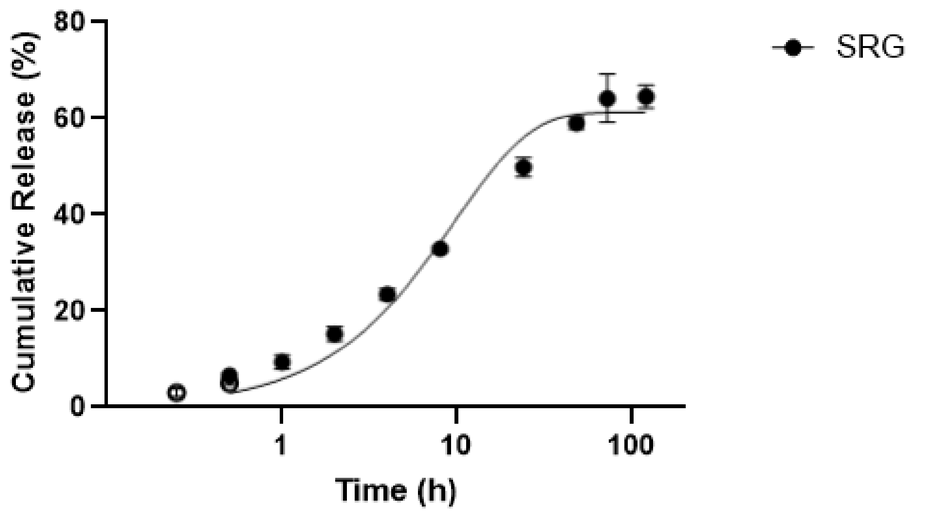
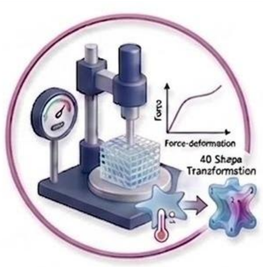


Figure 2. Cumulative release of a model drug surrogate from 3D-printed hydrogel discs.

- **Printability and reproducibility:** The hydrogel ink was successfully printed into reproducible constructs. Disc weights were highly consistent, with a mean of approximately 60.6 mg and a narrow range of 60.1-61.6 mg, supporting reproducible fabrication.
- **Sustained release profile:** The model small-molecule payload showed monotonic release over 120 h, reaching approximately 49.9% release at 24 h and 61.3% release at 120 h.
- **Kinetic behavior:** Release followed a one-phase association model with a fitted plateau of 61.3%, a rate constant of 0.103 h^{-1}, half-time of 6.75 h, and $R^2 = 0.967$.
- **Incomplete release suggests matrix retention:** The plateau confidence interval excluded complete release, indicating that approximately 39% of the payload remained within the hydrogel network after 120 h.

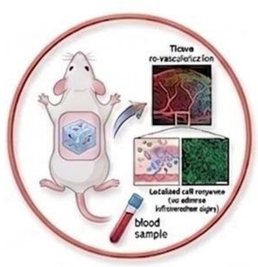
Next Steps

Formulation Characterization & Scalability
Characterize a broader range of additional formulations and assess key properties including rigidity, swelling, degradation profiles, and 3D print fidelity at scale.



Advanced Mechanical & 4D Analysis
Compare static 3D constructs with dynamic, future stimulus-responsive (e.g., pH, light) 4D formulations.

Drug-Specific Formulations & Cyto-Compatibility
Incorporate specific therapeutic agents and develop medical indications. Evaluate material medical indications. Evaluate cytocompatibility in cell models.



In Vivo Efficacy & Host Response
Perform comprehensive animal studies to evaluate the in vivo reaction to implanted materials and therapeutic efficacy.

Potential Application & Impact

- ✓ **Personalized therapy:** Bridging nanotechnology, materials science, and pharmacology to create customized architectures that account for individual disease morphology.
- ✓ **Minimizing Side Effects:** By restricting off-target drug release and activating exclusively at the intended site, these platforms can significantly reduce systemic side effects.
- ✓ **Future Applications:** Providing a foundation for developing printed, patient-specific medical devices across all medical fields.

Note: The precise formulation of the ink is currently withheld to safeguard intellectual property rights.

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