From Material Design to Biofabrication: Advancing Light-Based 3D Printing for Tissue engineering

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Introduction

Tissue engineering increasingly relies on the rational design of biomaterials combined with advanced 3D printing techniques. Light-based strategies, including digital light processing (DLP) and volumetric additive manufacturing (VAM), enable the fabrication of complex scaffolds with tunable mechanical and biological properties. This work presents the development and processing of synthetic (acrylate-endcapped urethane-based precursors (AUPs)) and natural polymers (thiolated gelatin-gelatin norbornene (GelSH-GelNB)) using these techniques to create functional constructs serving tissue engineering.

Experimental Methods

AUPs were developed by varying the polymer backbone (poly(ethylene glycol) (PEG) versus poly(propylene glycol) (PPG)) and endcap chemistry (di- vs. hexa-acrylate), yielding UPEG2, UPEG6, UPPG2, and UPPG6. Digital light processing parameters were optimized for each material to fabricate tubular and porous structures for cartilage and vascular construct applications.

For biofabrication, photo-crosslinkable gelatin-based hydrogels (10% (w/v), GelSH-GelNB, degree of substitution ~60%) were used as bioinks in VAM, containing MSCs ($1 \cdot 10^6$ cells·mL^{-1}). Lineage-specific differentiation was assessed after 21 days using Alizarin Red S (osteogenesis), Alcian Blue (chondrogenesis), and Oil Red O (adipogenesis).

Results and Discussion

DLP-printed AUP scaffolds showed tunable properties via backbone and acrylate variation.[1] Increased acrylate content lowered swelling (to 18%) and raised stiffness (to 5.3 MPa). PPG-based formulations offered superior stability and printing accuracy. Tubular constructs for vascular applications reached elastic moduli between 45 and 259 kPa, closely matching those of native vessels.[2] Cubic, porous constructs demonstrated mechanical profiles suitable for cartilage TE, highlighting the versatility of these materials.

VAM-printed gelatin hydrogels showed storage moduli from 206 Pa to 12.5 kPa, depending on the formulation. Constructs printed with 10% (w/v) GelNB-GelSH had compressive strengths up to 508 kPa and moduli around 21 kPa. Biofabricated scaffolds supported MSC proliferation over 21 days. Stiffer VAM constructs favored osteogenesis, while softer hydrogels promoted chondrogenic and adipogenic differentiation, confirming the ability of scaffold mechanics to guide MSC fate.[3]

Conclusion

Combining material design with advanced light-based fabrication allows the creation of complex scaffolds tailored for tissue engineering. Our results show that synthetic AUPs and natural gelatin hydrogels can be processed via DLP and VAM to meet mechanical, architectural, and biological demands. Volumetric bioprinting, in particular, represents a transformative step toward rapid, cell-friendly manufacturing for regenerative medicine.

References

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