

# Design and Physical Characterization of 3D-Printed Collagen Scaffolds for Regenerative Dentistry



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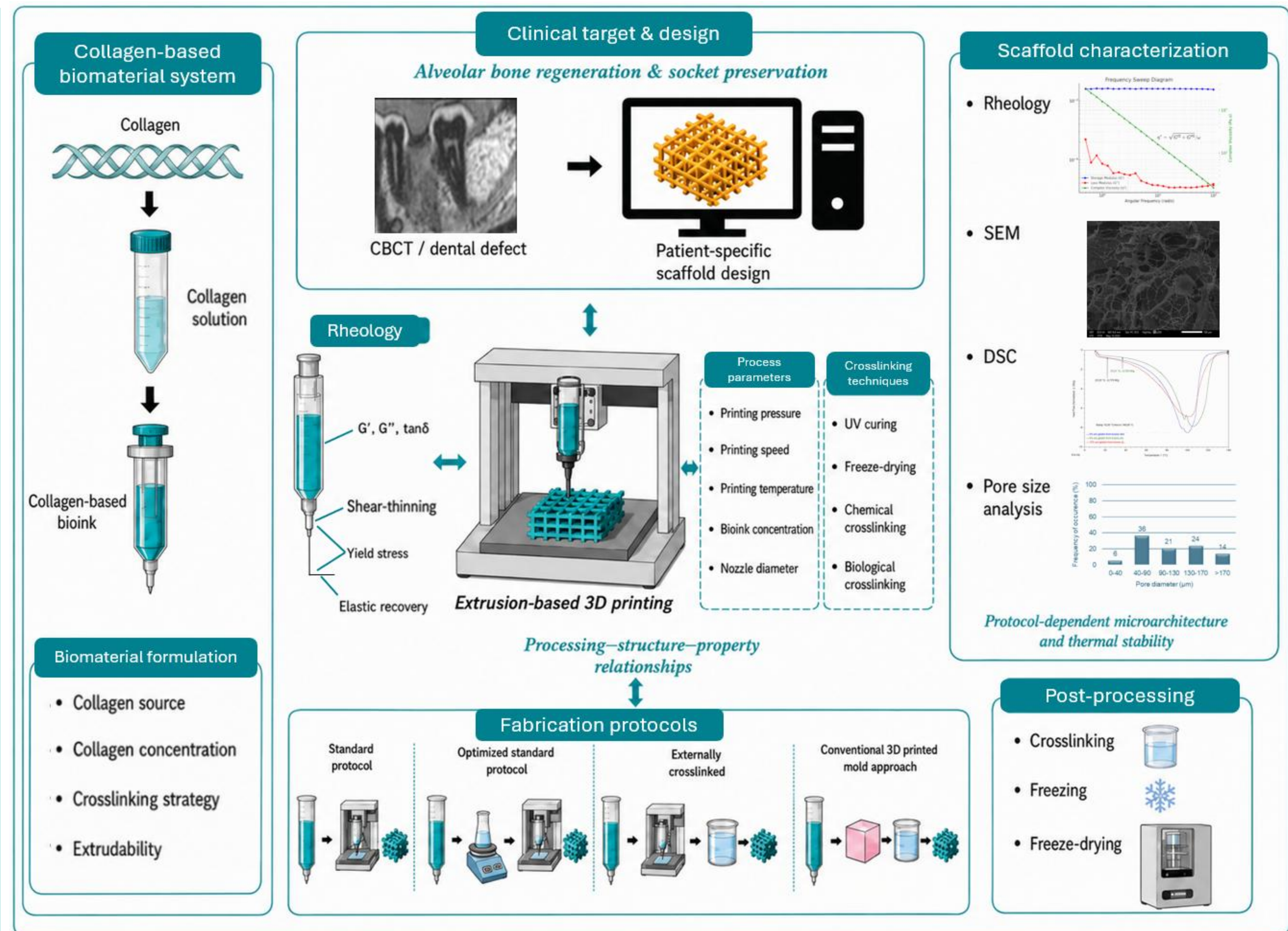
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## INTRODUCTION

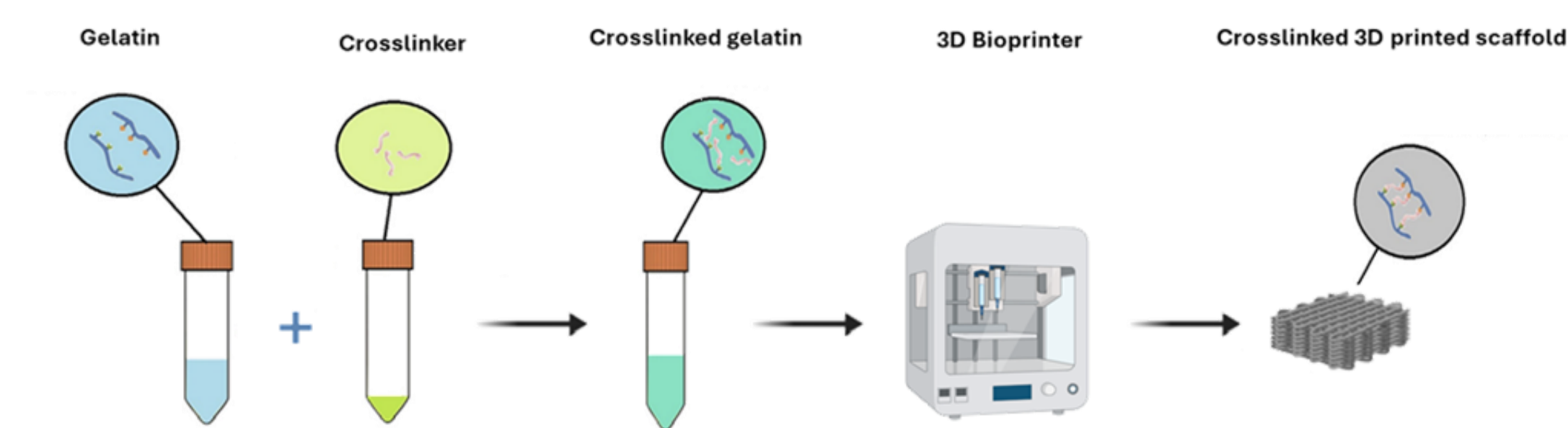
Regenerative dentistry aims to restore the structure and function of damaged oral and craniofacial tissues; however, the regeneration of alveolar bone remains a significant clinical challenge due to its limited intrinsic regenerative capacity and the complex anatomical and biological heterogeneity of the oral microenvironment. Although conventional grafting strategies are commonly applied, their clinical use may be constrained by donor-site morbidity, immunological complications, limited graft availability, and unpredictable integration. Collagen-based biomaterials represent a promising class of scaffolding matrices for tissue engineering, owing to their extracellular matrix-like composition, biocompatibility, biodegradability, and capacity to support cellular adhesion and tissue remodeling. When combined with extrusion-based three-dimensional bioprinting, collagen systems enable the fabrication of customized porous scaffolds with controlled architecture, thereby offering a biomimetic and patient-specific approach for alveolar bone regeneration.

**Objective:** To develop collagen-derived 3D-printed scaffolds and evaluate the effects of fabrication and crosslinking strategies on printability, viscoelastic stability, porous microarchitecture, and thermal behavior for regenerative dentistry applications.

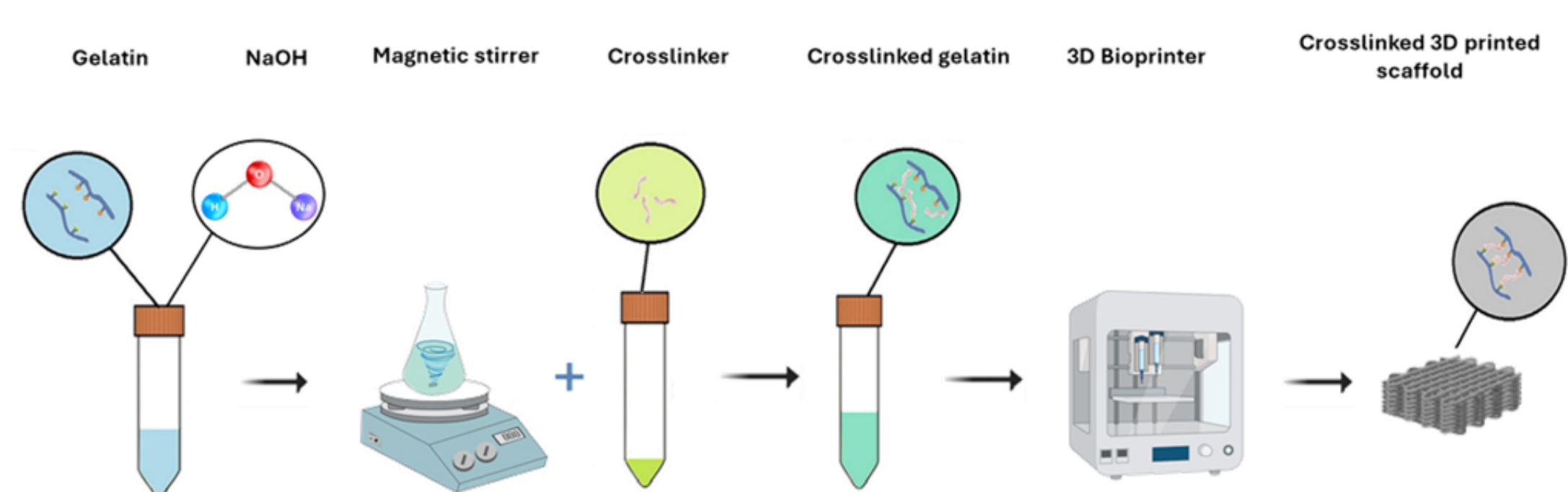


## MATERIALS & METHODS

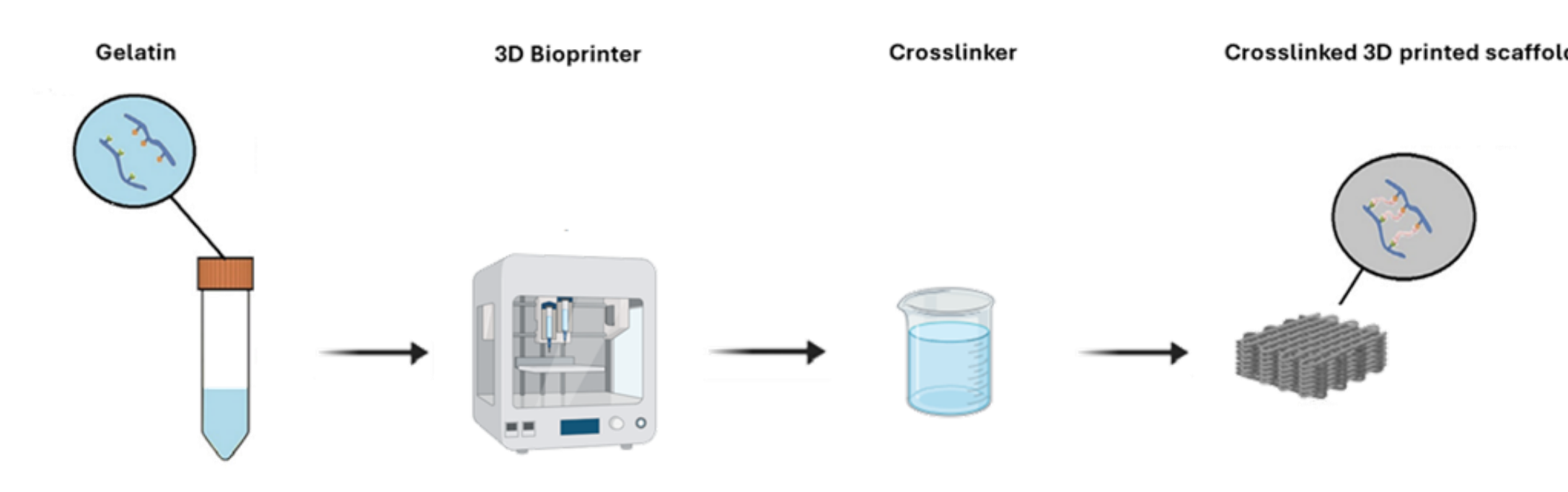
### Standard Protocol



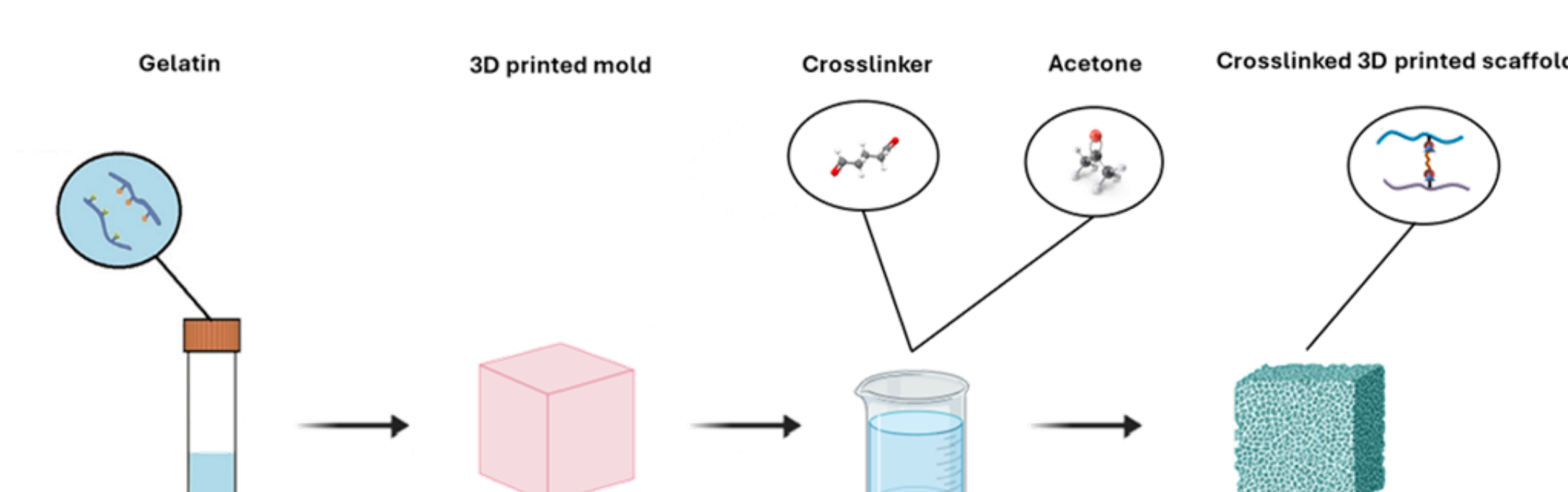
### Protocol A



### Protocol B

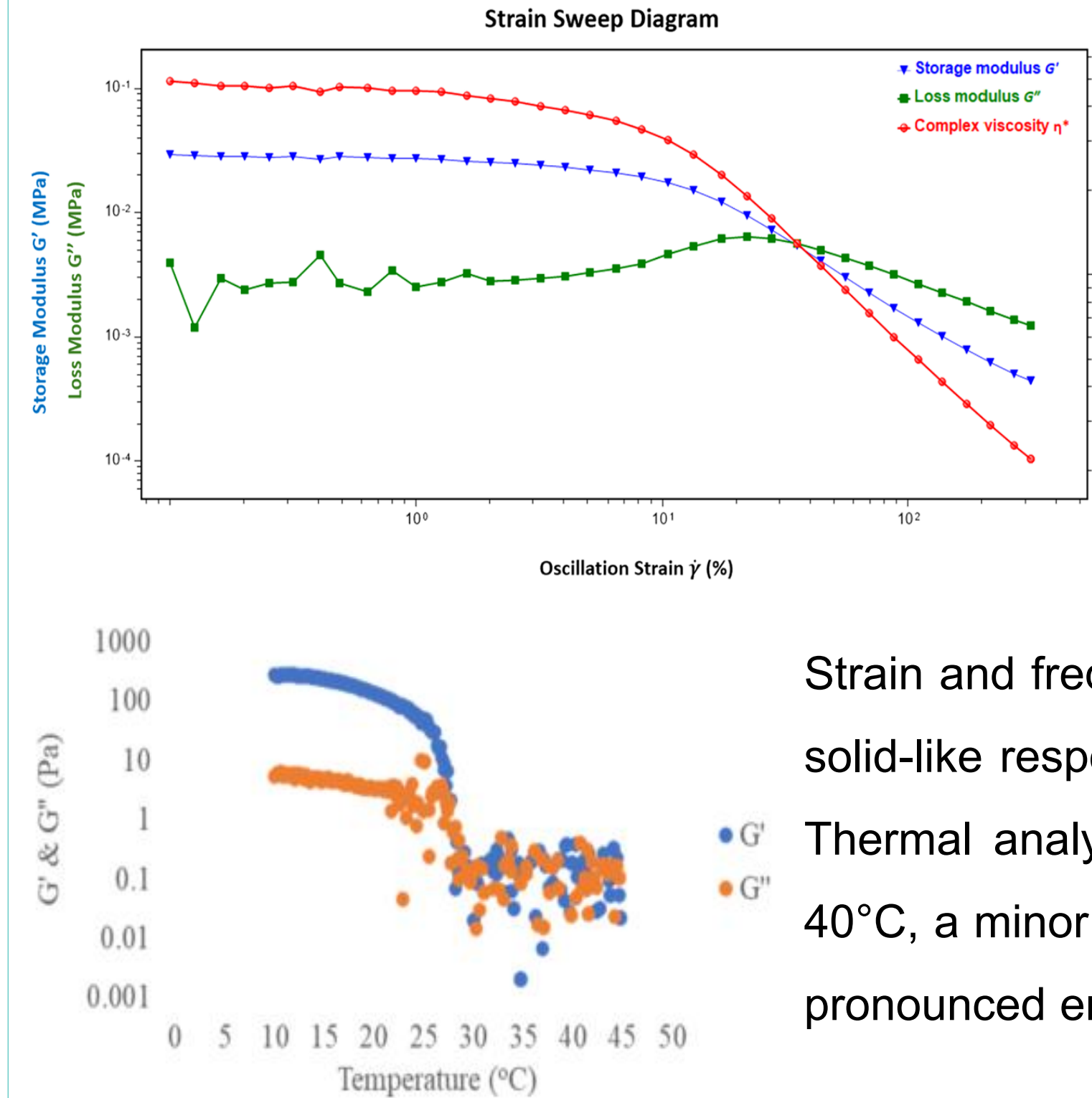


### Protocol C



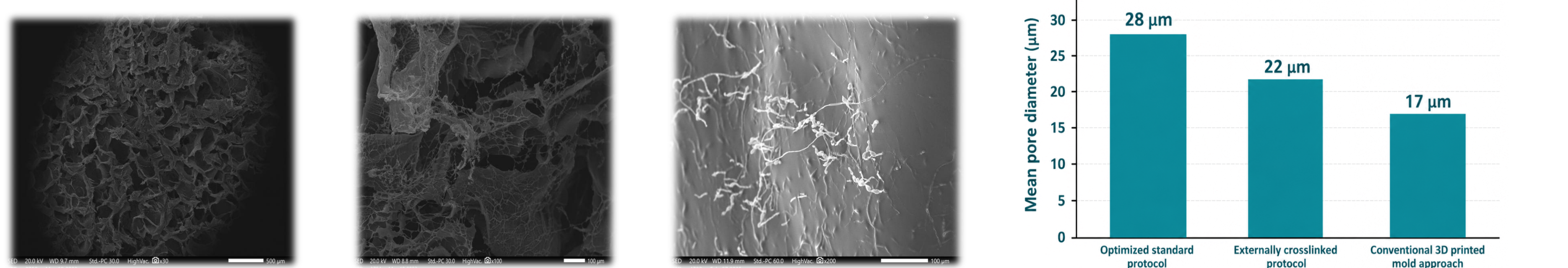
## RESULTS

### Rheology and Thermal Analysis



Strain and frequency sweep tests confirmed the hydrogel's viscoelastic behavior, showing a solid-like response at low deformation and increased flow under higher strain or frequency. Thermal analysis revealed temperature-dependent structural loss, with Tgel between 25–40°C, a minor endothermic peak at 30–35°C attributed to collagen triple-helix melting, and a pronounced endothermic event around 100°C corresponding to water vaporization.

### Morphology and Pore Architecture

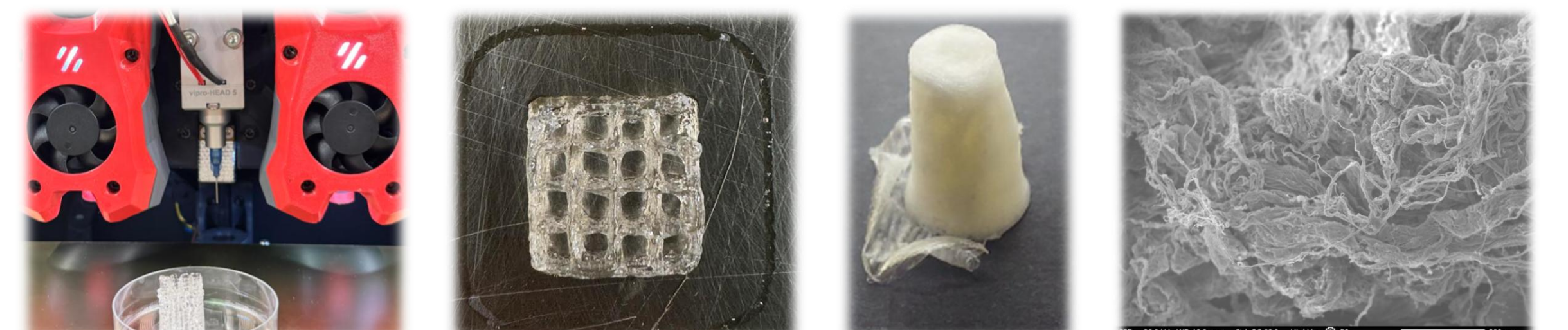


All fabrication protocols showed a predominance of small pores, enabling cell attachment and growth, while only a smaller proportion exceeded 90 μm. These larger pores are particularly important for oxygen and nutrient diffusion, as well as for promoting deeper cellular infiltration within the scaffold.

Protocol	Rheology	SEM	DSC	Conclusion
Standard / A	Increased mechanical strength	Highly porous and interconnected network	Enhanced thermal resistance and network stability	<b>Best overall</b>
B	Stable	Porous	Stable	Promising
C	Stable	Limited porosity	Stable	Needs optimization

## FUTURE DIRECTIONS

Ongoing research is exploring the optimal 3D-printing process parameters to improve scaffold fidelity and reproducibility, followed by dental-relevant evaluation of fluid absorption, hemocompatibility, cytocompatibility, and scaffold adaptation to post-extraction socket defects.



## RELATED LITERATURE

N. Karipidou, J.P.M. Gorley, C. Katrilaka, C. Manglaris, A.N. Tzavellas, M. Pitou, A. Cheva, N. Michailidis, E. Tsidiris, T. Choli-Papadopoulou, A. Aggeli. A Critical Review of Commercial Collagen-Based Scaffolds in Bone Regeneration: Functional Properties and Clinical Evidence from Infuse® Bone Graft. *Journal of Functional Biomaterials* 2025, 16(9), 313. <https://doi.org/10.3390/jfb16090313>