Hydrogel-Based Injectable and Printable Calcium Phosphate Cements (CPC) – Bioactive Glass (BG) Composites for Bone Tissue Engineering

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Introduction: Hydrogels play a central role in the development of injectable and printable systems for bone tissue engineering. Their ability to provide structural support, biocompatibility, and processability makes them ideal candidates for creating scaffolds that mimic the extracellular matrix. This study explores a hydrogel-based approach to design composite pastes with tailored rheological, mechanical and biological properties for bone regeneration.

Methods: A hydrogel matrix composed of biocompatible and biodegradable biopolymers—alginate, gelatine, and hyaluronic acid—was combined with calcium phosphate cements (CPCs) to enhance mechanical strength and mineralization potential. Bioactive glass particles (BG 45S5) were added to the composite to stimulate osteogenesis. The resulting composite pastes were rheologically characterized to evaluate their injectability and suitability for extrusion-based 3D bioprinting. After setting, printed and extruded constructs were analyzed using scanning electron microscopy (SEM), X-ray diffraction (XRD), mechanical compression tests, in vitro stability and bioactivity.

Results: The hydrogel matrix enabled smooth paste injection and stable 3D printing and a uniform dispersion of active components, contributing to the formation of interconnected porous structures, essential for bone tissue integration. Rheological tests confirmed adequate shear-thinning behavior. The incorporation of BG 45S5 significantly enhanced the bioactivity of the system, as evidenced by the formation of a hydroxyapatite-like layer at different time points after immersion in simulated body fluid. Mechanical testing confirmed the structural integrity of the constructs under compressive load, with compressive strength values between 3 and 5.5 MPa—comparable to trabecular bone—and an elastic modulus ranging from 300 to 700 MPa. Adjusting the hydrogel composition and BG content, setting times were controlled within the clinically acceptable range of 10–15 minutes for surgical use.

Conclusions: This study demonstrates the synergistic effect of hydrogels and bioactive glass in developing printable, injectable, and bioactive gel–cement composites with potential for bone tissue engineering.