

Advances in Hydrogel Bioprinting for Bone Tissue Engineering

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Submitted: 14 January 2024 – Revised version received: 15 January 2024 – Accepted: 16 January 2024 – Published online: Winter 2024

Abstract

Bone regeneration is a complex process involving the orchestration of multiple cellular and molecular events. In recent years, significant interest has emerged in utilizing three-dimensional (3D) printed hydrogels for bone tissue engineering, owing to their potential in mimicking the natural extracellular matrix and providing a platform for cell growth and differentiation. The use of bioprinted hydrogels for bone regeneration has garnered attention due to its potential in addressing critical-sized bone defects.

Keywords: Hydrogel; Bioprinting; Bone tissue engineering.

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Upon analysis of available literature, several novelties have recently been introduced for the application of 3D printed hydrogels in bone tissue engineering. These include the development of hydrogels with tunable rheological, physical, and mechanical properties to enhance 3D bioprinting quality and fidelity (1), the utilization of dual-crosslinked hydrogels with improved mechanical and biological properties for bone tissue engineering (2), and the incorporation of exosome-loaded hydrogel systems for prolonged delivery of bioactive components to bone tissue damage sites (3).

Bioprinted hydrogels have been designed with good biocompatibility and a 3D network structure, providing mechanical support and a basis for cell growth and tissue regeneration (4). Additionally, Wan et al. introduced time as the fourth dimension in 3D bioprinting to fabricate dynamic 3D-patterned biological architectures (5). Xie et al.'s study demonstrated the efficient engineering of osteocallus organoids for rapid bone regeneration within one month through digital light-processing (DLP) printing technology and stepwise-induction techniques (6).

Furthermore, Gupta et al. developed a novel triple-layered gel/polymer hybrid scaffold using a combination of gelatin/carboxymethyl-chitin/nano-hydroxyapatite and

polycaprolactone (PCL) through cryogenic 3D printing technology (7). This innovative approach aimed to address challenges related to fabricating scaffolds with high bioactivity and mechanical strength suitable for promoting osteogenesis while bearing load. Their results demonstrated impressive compression strength, modulus post-degradation, cellular attachment, proliferation, protein generation, and mineralization compared to conventional PCL scaffolds.

Moreover, the study by Khojasteh et al. demonstrated that the combination of the alginate-gelatin hydrogel with freeze-dried bone allograft nanoparticles and rat bone marrow mesenchymal stem cells (rBMSCs) showed excellent adhesion, proliferation, and differentiation of the cells (8). The rBMSCs-loaded hydrogel exhibited comparable bone regeneration to the rBMSCs-loaded FDBA group, surpassing the other treatment groups. Hence, 3D-printed hydrogels could be a promising approach for enhancing bone regeneration in critical-sized bone defects such as maxillary alveolar clefts and mandibular segmental defects.

In conclusion, recent advancements in 3D printed hydrogels for bone tissue engineering have shown promising developments in addressing key challenges, such as achieving optimal mechanical properties while promoting osteogenesis within engineered scaffolds. While these innovations hold great potential for future clinical translation into reconstructive surgeries involving non-load-bearing or moderate load-bearing bone defects, such as sinus lift procedures or craniomaxillofacial reconstructions, further comprehensive preclinical investigations are warranted before considering human applications.

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How to cite:

Bastami F. *Advances in hydrogel bioprinting for bone tissue engineering.* *J Dent Sch* 2023;40(2).