Multifunctional ADA-GEL hydrogels reinforced with iron loaded dendritic bioactive glass nanoparticles for bone regeneration

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Introduction: Bone-related diseases and injuries, including osteoporosis, osteomyelitis, and fractures, affect millions globally and pose increasing challenges to public health due to the aging population. Conventional treatments, such as autologous bone grafts have a limited availability, highlighting the need for alternative strategies [1], [2]. Bone tissue engineering offers a promising solution by combining biomaterials, cells, and signaling factors to create scaffolds that mimic the native bone extracellular matrix. Hydrogels composed of natural polymers, particularly when reinforced with bioactive glasses, have gained attention for their tunable mechanical properties, biocompatibility, and ability to support osteogenesis and angiogenesis [3]. In this context, we developed iron-loaded dendritic mesoporous bioactive glass nanoparticles incorporated into alginate-di-aldehyde–gelatin (ADA-GEL) hydrogels, evaluating their physicochemical properties and biological performance for bone regeneration.

Materials and methods: Dendritic mesoporous bioactive glass nanoparticles (DMBGNs) were synthesized by first preparing dendritic mesoporous silica nanoparticles (DMSNs) using a dual surfactant template method in a solvent-free system [4]. Calcium and iron were incorporated by dispersing DMSNs in ethanolic solution of the calcium nitrate, respectively iron nitrate. ADA-GEL hydrogels were prepared following the protocol established at the FAU Institute of Biomaterials [5]. Briefly, 5% oxidized alginate and 7.5% gelatin were mixed in DPBS (1:1 ratio). 0.1% DMBGNs were incorporated into ADA prior to gelatin addition, and printability was assessed using a BioScaffolder 2.1 printer, printing a 4-layer scaffolds.

Results: Dendritic mesoporous bioactive glass nanoparticles were synthesized by loading different concentrations of Ca^{2+} and Fe^{3+}, resulting in flower-like porous structures and high surface areas. When incorporated into ADA-GEL hydrogels, nanoparticles maintained their bioactivity, supported by apatite formation in SBF. FTIR and XRD confirmed crosslinking and structural integration, while SEM revealed porous, interconnected hydrogel morphology. Degradation and mechanical tests highlighted improved structural stability in Fe-containing hydrogels, particularly the 0.1M Fe composition exhibited the best printability and mechanical properties, making it a promising candidate for bone tissue engineering.

Conclusions: The results demonstrate that Fe-loaded DMBGNs can be effectively synthesized and integrated into ADA-GEL hydrogels, preserving their mesoporous structure and enhancing mechanical properties, printability, and bioactivity. Among tested formulations, lower concentration of iron loaded particles showed the most promising performance for bone tissue engineering applications. These findings highlight the potential of ion-modified dendritic bioactive glass nanoparticle containing hydrogels as multifunctional bioinks for regenerative medicine.

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