# Bioactive and Nanostructured Hydrogels for Personalized Bone Regeneration

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**Abstract**

Critical-size bone defects represent a major clinical challenge, for which conventional solutions are limited by availability, biological risks, and insufficient tissue integration. In this context, composite biomaterials offer a promising alternative by combining structural support with bioactive cues required for bone regeneration.

The central objective of this doctoral thesis is the development of nanostructured composite hydrogels, designed as multifunctional systems tailored for personalized bone tissue regeneration. The conducted research explores, over four complementary experimental directions, the functionalization of hydrogels with natural-origin bioactive compounds, architectural reinforcement using fibrillar structures fabricated via melt electrowriting, incorporation of carbon-based nanoparticles and osteoinductive molecules, as well as the development of multicomponent formulations for bioprinting.

The results demonstrate the possibility of controlled modulation of the rheological properties and printability of the developed formulations, as well as the architecture and physical, mechanical, and biological characteristics of the resulting hydrogel scaffolds. These properties directly influence cellular adhesion, proliferation, and osteogenic differentiation. Overall, the thesis outlines a versatile multiscale strategy for the fabrication of bioactive composite hydrogels, with significant potential for personalized bone regeneration.