Nanomaterial-Driven Enhancement of Stem Cell Differentiation: Emerging Tools for Tissue Engineering

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Abstract

Introduction *Scaffolds provide essential structural support for cell adhesion and guide cellular growth and organization toward the formation of a desired three-dimensional structure. Among the various cell sources, stem cells hold a superior position due to their significant capacity for self-renewal and differentiation [1]. induced pluripotent stem cells (iPSCs) in particular, overcome the ethical and immunological concerns associated with ESCs and are therefore considered a promising alternative, due to their structural and molecular similarity to embryonic stem cells, along with their high differentiation capacity [2]. This strategy makes it possible to generate highly pluripotent, patient-specific cells without the need for invasive procedures or the ethical issues associated with embryonic cells, while also reducing the risk of immune rejection [1]. Recent advancements in nanotechnology have made it possible to design and produce multifunctional biomaterials that are able to direct and modify stem cell behavior. The integration of nanomaterials with stem cell engineering has provided solutions to several major challenges, including targeted control of differentiation, immune regulation, stem cell scarcity, and the fabrication of complex tissues [3].*

Methods *In this study, recent advances in the application of nanotechnology to address key challenges in tissue engineering are reviewed through a search conducted in the Google Scholar database.*

Results *In recent years, a growing body of research has demonstrated that nanomaterials can facilitate stem cell proliferation and differentiation, and extensive efforts has been undertaken to explore their possible modulating manners and mechanisms on stem cell differentiation [4]. Previous studies have shown that nanoparticles approximately 50 nm in size are internalized by cells at higher level [5]; whereas smaller nanoparticles are more cytotoxic, and larger nanoparticles are less efficiently incorporated by cells [6, 7]. Additionally, nanoparticles morphology has been shown to significantly influence cellular uptake, which may affect stem cell differentiation [8]. Nanomaterials-based 3D scaffolds, through their mechanical properties and chemical composition, regulate the proliferation and differentiation capacity of stem cells [9] and offer an optimized microenvironment for cell–cell and cell-nanomaterials interactions. By adjusting these properties, such scaffolds can be engineered to direct stem cell differentiation toward specific lineages [10].*

Conclusion *Nanomaterials can effectively modulate drug-release profiles and microenvironments involved in stem cell differentiation, thereby improving both therapeutic efficiency and safety [11]. The hybrid construct of nanomaterials and stem cell approaches has generated promising opportunities for the treatment of various diseases, including cardiovascular disorders, neurodegenerative diseases, and bone tissue repair and regeneration [12, 13, 14, 15].*

Key words: *Scaffold, Nanomaterial, Stem cell, Regenerative medicine, Tissue engineering.*

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