Chapter 1
Nanomaterials:
Nanoparticles, Nanofibers, and their Biomedical Applications

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ABSTRACT

The impact of nanomaterials in healthcare has been transformative. In drug delivery, they enable targeted therapeutic delivery, improved drug solubility, and controlled release profiles, significantly enhancing treatment efficacy while reducing side effects. In tissue engineering, nanomaterial scaffolds provide ideal environments for cell growth and tissue regeneration, mimicking natural extracellular matrix structures. Diagnostic imaging has benefited from nanomaterial-based contrast agents that offer enhanced sensitivity and multimodal imaging capabilities. Their small size allows them to interact with cellular components, while their high surface area provides platforms for functionalization with targeting molecules, drugs, or imaging agents. The chapter discusses the ability to engineer these materials with specific surface properties for biomedical applications. It presents a comprehensive review of classification, properties, synthesis techniques, characterization techniques and applications of nanoparticles and nanofibers.

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1. INTRODUCTION TO NANOMATERIALS

Nanomaterials have revolutionized modern science and technology through their unique properties at the nanoscale (1-100 nm). Because of their extremely high surface-to-volume ratio and properties of quantum effects, these nanoscale structures differ from bulk materials in their physical, chemical, and biological properties (Fu, 2024). Their capacity to be precisely manipulated in terms of composition, size, and shape has led to significant developments in a few domains, most notably biomedical applications. Advances in synthesis methods, better characterisation tools, and a better knowledge of how these materials interact with biological systems are all responsible for the exponential increase in nanomaterial research and development over the past few decades. Unprecedented control over the characteristics and behaviours of materials has been made possible by the capacity to change them at the molecular level. Because of this control over elements like tissue integration, drug release kinetics, and imaging contrast enhancement, nanomaterials are very useful in healthcare applications (Arif, 2024). Two basic types of nanomaterials that have demonstrated remarkable potential in biomedicine are nanoparticles and nanofibers. Applications requiring targeted administration and cellular penetration are well suited for nanoparticles, which are often spherical or almost spherical in shape. Nanofibers are extremely useful in tissue engineering and wound healing applications because of their high aspect ratio and linked structure. Numerous techniques, including as chemical, physical, and biological approaches, can be used to synthesize both groups; each has unique benefits and drawbacks (Goyal, 2016).

Nanomaterials have had a revolutionary effect on healthcare. They greatly increase treatment efficacy while lowering negative effects by enabling focused therapeutic delivery, enhanced drug solubility, and controlled release profiles in medication delivery. By simulating natural extracellular matrix architecture, nanomaterial scaffolds in tissue engineering offer optimal conditions for cell proliferation and tissue regeneration. Nanomaterial-based contrast agents, which provide improved sensitivity and multimodal imaging capabilities, have helped diagnostic imaging (Kurul, 2025). The molecular characteristics of nanomaterials have made it possible to manipulate biological interactions in a way that has never been possible before. They can interact with biological components due to their small size, and they can be functionalized with medicines, imaging agents, or targeting molecules thanks to their large surface area. The capacity to design these materials with certain surface characteristics guarantees that they are compatible with biological systems while preserving their functional capacities (Zhang, 2012). With new developments in smart nanomaterials that react to stimuli, enhanced targeting techniques, and the creation of theragnostic platforms that combine therapeutic and diagnostic capabilities, the area is still developing. Enhancing safety profiles, creating green synthesis

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