



Biomedical applications of chitosan nanocarriers: Design strategies and translational challenges

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ABSTRACT

Chitosan, a natural biopolymer derived from chitin, has gained significant attention as a versatile material for nanocarrier development due to its biocompatibility, biodegradability, and tunable physicochemical properties. This review highlights the design, challenges, and biomedical applications of chitosan-based nanocarriers, emphasizing their role in advanced drug delivery, diagnostics, and regenerative medicine. Various nanostructures, including nanoparticles, nanogels, and nanofibers, can be fabricated using techniques such as ionic gelation, emulsion-based synthesis, nanoprecipitation, and electrospinning to meet specific therapeutic needs. These systems demonstrate enhanced mucoadhesion, targeted delivery, and the ability to cross biological barriers like the blood–brain barrier, enabling efficient transport of chemotherapeutics, nucleic acids, and vaccines through noninvasive routes. In addition, chitosan exhibits intrinsic antimicrobial properties, while its anti-inflammatory and antioxidant effects can be further improved through chemical modification or combination with bioactive agents, expanding its use in wound healing and tissue engineering. However, challenges such as poor solubility at physiological pH, environmental sensitivity, scalability limitations, and regulatory hurdles restrict clinical translation. Approaches including chemical modification, crosslinking, and optimized storage and sterilization have shown promise in enhancing stability. This review integrates design strategies with translational and regulatory considerations, offering a comprehensive and forward-looking perspective.

ARTICLE HISTORY

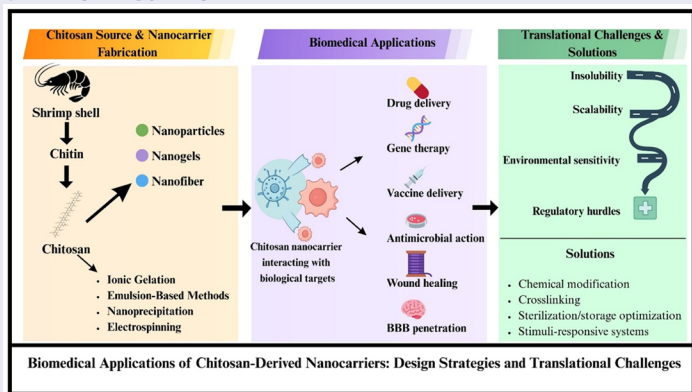
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GRAPHICAL ABSTRACT



1. Introduction

Nanotechnology has profoundly influenced biomedical sciences, with the global nanomedicine market expected to reach 687.64 billion by 2035, which enables the development of advanced materials for diagnostics, drug delivery, and therapy.^[1] Even though fabrication methods for nanoparticles have advanced significantly, large-scale manufacturing

remains challenging due to batch-to-batch variability, high reagent costs, and high sensitivity.^[2] Among the numerous analyzed nanostructures, nanocarriers have proven to be a promising platform, as they enable improvements in the efficacy, stability, and bioavailability of therapeutic agents. They represent a colloidal drug carrier system, which exhibits a large surface-to-volume ratio, thereby improving