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Nanotechnology-based Drug Formulations for Enhanced Oral Bioavailability and Controlled Release

Xiao Wang*

Department of Pharmaceutical Sciences, University of Haiti, Port-au-Prince, Haiti

Abstract

Nanotechnology has emerged as a promising avenue for revolutionizing drug delivery, particularly in enhancing oral bioavailability and achieving controlled release of therapeutic agents. Traditional drug formulations face numerous challenges, including poor solubility, limited stability and inefficient absorption in the gastrointestinal tract, which can significantly affect drug efficacy and patient compliance. Nanotechnology offers innovative solutions by harnessing the unique properties of nanoscale materials to overcome these limitations and improve the pharmacokinetic profiles of orally administered drugs. At the forefront of nanotechnology-based drug formulations are nanoparticles, which are typically in the range of 1-1000 nanometers in size. These nanoparticles can be fabricated from a variety of materials, including polymers, lipids and inorganic compounds, each offering distinct advantages in terms of drug loading capacity, biocompatibility and tunable release kinetics.

Keywords: Nanotechnology • Drug formulations • Oral bioavailability

Introduction

By encapsulating drug molecules within nanoparticles or conjugating them to the nanoparticle surface, researchers can enhance drug solubility, protect drugs from enzymatic degradation in the gastrointestinal tract and facilitate their transport across epithelial barriers for improved absorption. One of the key challenges in oral drug delivery is overcoming the low aqueous solubility of many therapeutic compounds, particularly hydrophobic drugs. Nanotechnology provides a solution through the design of nanoscale drug delivery systems that can encapsulate poorly soluble drugs within a hydrophilic shell or matrix, thereby increasing their dispersibility in aqueous media and enhancing their solubility and dissolution rates upon administration [1]. For example, lipid-based nanoparticles such as liposomes and solid lipid nanoparticles (SLNs) have been extensively investigated for their ability to encapsulate lipophilic drugs within their lipid bilayers or cores, thereby improving their bioavailability and therapeutic efficacy.

Moreover, nanotechnology enables the design of drug delivery systems with tailored release profiles, allowing for sustained or controlled release of therapeutic agents over an extended period. This controlled release can help maintain therapeutic drug levels within the therapeutic window, minimize fluctuations in plasma drug concentrations and reduce the frequency of dosing, thereby improving patient compliance and reducing the risk of adverse effects. Various strategies, including the use of biodegradable polymers, stimuli-responsive materials and nanoparticle surface modifications, have been employed to achieve controlled drug release from nanotechnology-based formulations [2]. For instance, polymeric nanoparticles can be engineered to release drugs in response to specific stimuli such as pH, temperature, or enzymatic activity present in the gastrointestinal tract, thereby providing site-specific drug delivery and minimizing off-target effects.

***Address for Correspondence:** Xiao Wang, Department of Pharmaceutical Sciences, University of Haiti, Port-au-Prince, Haiti, E-mail: wang.xiao65@wiley.de*

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Literature Review

Furthermore, nanotechnology offers the potential to enhance drug targeting and tissue specificity through active and passive targeting strategies. Passive targeting exploits the Enhanced Permeability and Retention (EPR) effect, whereby nanoparticles preferentially accumulate in tumor tissues or inflamed regions due to leaky vasculature and impaired lymphatic drainage. By optimizing the size, shape and surface properties of nanoparticles, researchers can enhance their circulation time in the bloodstream and maximize their accumulation at the target site, thereby improving therapeutic outcomes while minimizing systemic toxicity [3]. Active targeting, on the other hand, involves the functionalization of nanoparticles with targeting ligands such as antibodies, peptides, or aptamers that can recognize and bind to specific receptors or biomarkers overexpressed on the surface of target cells or tissues. This targeted approach enables precise delivery of therapeutic agents to diseased tissues while sparing healthy cells, thereby enhancing therapeutic efficacy and reducing off-target effects.

In addition to improving oral bioavailability and controlled release, nanotechnology-based drug formulations offer several other advantages, including improved stability, reduced dosing frequency and enhanced safety profiles. By encapsulating drugs within nanoparticles, researchers can protect them from degradation by enzymes and harsh gastrointestinal conditions, thereby improving their stability and prolonging their shelf life [4]. This enhanced stability is particularly beneficial for the formulation of biologics, including peptides, proteins and nucleic acids, which are prone to degradation and denaturation in physiological environments. Moreover, the nanoscale size of drug delivery systems enables them to bypass efflux transporters and evade first-pass metabolism in the liver, leading to increased systemic exposure and bioavailability of orally administered drugs.

Discussion

Furthermore, nanotechnology-based drug formulations offer the potential for combination therapy and personalized medicine by co-encapsulating multiple drugs or therapeutic agents within a single nanoparticle platform. This approach allows for synergistic interactions between co-delivered drugs, simultaneous targeting of multiple disease pathways and customization of treatment regimens based on individual patient characteristics and therapeutic needs [5]. For example, nanotechnology-based combination therapies have been explored for the treatment of cancer, infectious diseases and inflammatory disorders, where the simultaneous delivery of chemotherapeutic

agents, targeted therapies and immunomodulators can enhance therapeutic efficacy and overcome drug resistance mechanisms.

Despite the significant promise of nanotechnology-based drug formulations for enhancing oral bioavailability and controlled release, several challenges and considerations must be addressed to facilitate their translation from the laboratory to the clinic. These include scalability and reproducibility of manufacturing processes, safety and biocompatibility of nanoparticle materials, regulatory approval and commercialization pathways and cost-effectiveness compared to conventional drug delivery systems [6]. Additionally, the potential long-term effects of nanoparticle exposure on human health and the environment warrant further investigation to ensure the safety and sustainability of nanotechnology-based drug delivery platforms.

Conclusion

In conclusion, nanotechnology holds tremendous potential for revolutionizing oral drug delivery by overcoming the inherent limitations of traditional drug formulations and improving the pharmacokinetic profiles of therapeutic agents. Nanoparticle-based drug delivery systems offer unique advantages in terms of enhancing oral bioavailability, achieving controlled release and enabling targeted delivery to diseased tissues. By harnessing the principles of nanotechnology, researchers can develop innovative drug delivery platforms that enhance therapeutic efficacy, improve patient compliance and pave the way for personalized medicine and precision therapeutics in the treatment of various diseases. Continued research and development in this field are essential to realize the full potential of nanotechnology-based drug formulations and translate them into clinically impactful therapies for improving human health and well-being.

Acknowledgement

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Conflict of Interest

None.

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