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Role of Biodegradable Nanoparticles in Pulmonary Drug Delivery for Respiratory Diseases like COPD and Asthma

A. Sheela Devi, Vishnu Kiran Manam
KARPAGA VINAYAGA COLLEGE OF ENGINEERING AND TECHNOLOGY, DGM - R&D IB GROUP

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[1]A. Sheela Devi, Professor, Department of Biotechnology, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, Tamil Nadu, India. sheeladevi.kvcet@gmail.com

[2]Vishnu Kiran Manam, Senior Scientist / DGM - R&D IB Group, Indamara, Rajnandgaon, Chhattisgarh - 491411. dna.vishnu@gmail.com

Abstract

Biodegradable nanoparticles coupled with artificial intelligence (AI) represent a groundbreaking approach in the field of pulmonary drug delivery, offering novel solutions for the treatment of chronic respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD). This chapter explores the potential of these advanced technologies to revolutionize the management of respiratory disorders by enabling targeted, controlled, and efficient drug delivery systems. By leveraging the unique properties of biodegradable nanoparticles, the development of inhalable therapies can be optimized to deliver drugs directly to the lungs, reducing systemic side effects and enhancing therapeutic efficacy. The integration of AI further enhances the design, formulation, and predictive modeling of these nanoparticle-based systems, ensuring precision in drug delivery and personalized treatment strategies.

The intersection of nanotechnology and AI holds significant promise in overcoming the limitations of conventional treatment modalities, including poor bioavailability, short half-life, and inadequate targeting of disease sites. Moreover, AI-powered simulations can accelerate the development process by enabling real-time analysis of particle behavior, interaction with biological systems, and predicting patient-specific responses. However, successful translation from laboratory innovations to clinical applications requires the convergence of expertise across multiple disciplines, including nanotechnology, pulmonology, pharmacology, and regulatory science.

Ethical, regulatory, and socio-economic challenges must be addressed to ensure the safe, equitable, and widespread adoption of these technologies. Stakeholder collaboration, robust regulatory frameworks, and careful consideration of data privacy and patient consent are essential to realizing the full potential of AI-nanoparticle therapies. The chapter concludes with a discussion on the future prospects and the transformative role these integrated technologies will play in reshaping the treatment landscape for respiratory diseases.

Keywords: biodegradable nanoparticles, artificial intelligence, pulmonary drug delivery, chronic obstructive pulmonary disease, asthma, targeted therapy.

Introduction

Biodegradable nanoparticles and artificial intelligence (AI) are emerging as powerful tools in the treatment of chronic respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD) [1]. These diseases, characterized by airway inflammation, reduced lung function, and frequent exacerbations, remain major public health concerns worldwide [2]. Traditional treatment modalities, such as inhalers and systemic drugs, often fail to deliver sustained therapeutic effects, resulting in suboptimal patient outcomes [3]. The integration of biodegradable nanoparticles in pulmonary drug delivery systems provides a promising solution by offering targeted, controlled, and efficient delivery of therapeutic agents directly to the lungs [4]. This approach not only improves drug bioavailability but also minimizes the risk of systemic side effects, ensuring a more effective treatment strategy for patients with respiratory conditions [5].

Biodegradable nanoparticles are designed to overcome the limitations of conventional drug delivery systems [6]. Their small size and ability to encapsulate a variety of drugs make them ideal carriers for pulmonary delivery [7]. These nanoparticles can be engineered to release drugs in a controlled manner, allowing for sustained therapeutic effects over extended periods [8]. This reduces the frequency of drug administration, which is particularly beneficial for chronic diseases that require long-term management [9]. Biodegradable nanoparticles degrade naturally in the body, minimizing concerns about long-term accumulation and toxicity. As a result, they provide a safer alternative to other drug delivery systems, making them highly suitable for use in chronic respiratory disease treatment [10].

Artificial intelligence plays a crucial role in optimizing the design, formulation, and delivery of biodegradable nanoparticles for respiratory therapies [11]. AI algorithms can analyze large datasets to predict how nanoparticles will behave within the human body, improving the precision and efficiency of drug delivery [12]. Through machine learning, AI can assist in the identification of ideal nanoparticle characteristics, such as size, shape, and surface properties, that are most likely to achieve optimal drug deposition in the lungs [13]. AI models can help personalize treatment strategies by predicting individual patient responses based on their unique physiological and genetic profiles [14]. This precision medicine approach holds the potential to enhance therapeutic outcomes and reduce adverse effects by tailoring treatments to the specific needs of each patient [15].