Sustainable Nanotechnology

Strategies, Products, and Applications

Edited by
Yashwant V. Pathak • Govindan Parayil
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2

The Road to Sustainable Nanotechnology: Challenges, Progress, and Opportunities

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2.1 Introduction

Advances in nanotechnology are generating novel nanomaterials (NMs) with extraordinary characteristics that can enrich and enhance the applicability of NMs in various sectors. As new uses are being explored on a daily basis in various diversified areas such as medicine, agriculture, automotive, and energy, it poses numerous challenges to environmental sustainability [1]. Application of NMs are improving energy conservation and increasing efficiency, productivity and profits of industrial and health sectors with lower environmental impact [2]. Using NMs in current technology can improve economic and environmental aspects with various applications. Simultaneously, it is accepted that the use of NMs increases the various challenges in human safety and regulations in various countries [3].

In 2011, a group of researchers, students, and government staff from a multidisciplinary area came together to check the effect of science and engineering on developing a new path with sustainable future. This panel of scientists had done research on nanotechnology and correlated it to various aspects of sustainability such as society, environment, and economy [4]. The Sustainable Nanotechnology Organization (SNO) has come into existence with the aim to support the advances in sustainable nanotechnology. It also promotes the progression of scientific work in the field of nanotechnology for safety, environment, and health. However, every developing technology is required to be balanced between the benefits for human and its undesired effects on environment and life [5].

As advances in nanotechnology continue, the research is progressing on many issues regarding sustainability for next decades. Recent advances in nanotechnology report worldwide challenges in various applications such as purification of water, management of greenhouse effect, and manufacturing using green chemistry [6]. Because of the significant physicochemical properties of NMs, it gives us more effective solution for sustainable technologies. In comparison with bulk materials, NMs have effective larger surface area. The synthesis of NMs with incorporation of functional group can increase their affinity toward a given compound with improved efficiency. NMs can also give us an opportunity to enhance them with improved optical, magnetic, and catalytic properties [7]. For instance, in the case of semiconductor quantum dots, the variation in fluorescence emission capacity depends strongly on the difference in particle size. Nanoscale materials have different physicochemical and biological properties, which meet many growing needs of society. By exploring the novel development of NMs with new properties, it can be possible to enhance the performance of materials significantly, in terms of achievement of more product performance using less material [8, 9]. Development of NMs using required approach having ecofriendly characteristics is need of todays industries like textiles, paints and biomedical [10]. The available methods used for preparation of nanostructured materials are ultrasonication, reverse-phase micelle, microwave assisted techniques, and deposition of vapour by chemical and physical means [11]. Nano metal oxides such as Al_2O_3, TiO_2, and SiO_2 have been efficiently obtained from the nature and is one of the best examples of such techniques [12]. Today, the available solar cells having effectiveness of 10–25% are made up of silicon [13]. The cost of a solar cell can be reduced by improving its efficiency, which makes it more economically competitive [14]. By using nanostructured surface for reflectivity in solar cell devices, the antireflection ability may be enhanced

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5

Improving Sustainable Environment of Biopolymers Using Nanotechnology

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5.1 Introduction

Biopolymers are polymeric biomolecules that contain monomeric units that are covalently bonded to shape greater particles. The prefix "bio" signifies they are biodegradable materials made by living creatures. A wide kind of materials generally obtained from natural sources like microorganisms, plants, or trees are regularly portrayed utilizing the expression "biopolymer". Materials delivered by synthetic chemistry from biological/natural sources like vegetable oils, sugars, fats, resins, proteins, amino acids, at that point on likewise can be portrayed as biopolymer [1].

When contrasted with synthetic polymers which have a less difficult and more irregular structure, biopolymers are complex atomic gatherings that receive exact and characterized 3D shapes and structures. This is one significant property that makes biopolymers dynamic atoms in vivo. Their characterized shape and structure are surely keys to their working function. For instance, hemoglobin would not have the option to convey oxygen in the blood in the event that it was not collapsed in a quaternary structure. The primary property that recognizes biopolymers from nonrenewable energy source determined polymers is their sustainability, particularly when joined with biodegradability. Biodegradable biopolymers from renewable resources have been incorporated to give options in contrast to fossil-fuel-based polymers. They are mainly obtained from starch, sugar, natural fibers, or other natural biodegradable segments in different formulation quality. The biopolymers are debased by an introduction to microorganisms in the soil, compost, or marine residue. Besides, exposing biodegradable biopolymers to garbage removal by using their attribute of being degradable by the microscopic organisms especially bacteria in the ground fundamentally diminishes the release of CO_2 contrasted with conventional incineration. In this way, the utilization of biodegradable biopolymers from the perspective of global warming prevention. Lately, with the basic circumstance of the worldwide condition worsening because of global warming, the development of systems with maintainable utilization of materials has been accelerated from the perspective of adequately utilizing limited carbon resources and saving limited energy resources. Moreover, the expense of oil feedstocks has risen drastically and there is a rising purchaser enthusiasm for utilizing "green" (or renewable resources) as the reason for consumer items [2].

One of the rapidly developing materials areas in the last few years has been the manufacturing of polymers from sustainable resources also can be said as renewable resources. Their advancement is filled by the potential these polymers hold to supplant fossil-fuel-based polymers. The primary explanations behind this drive can be summed up as follows:

1) insufficient fossil-fuel resources;
2) pricing uncertainty of fossil fuels;
3) the commitment of the petroleum derivative as a feedstock to environmental change;
4) its infrequent role as a political weapon; and
5) its relationship with the garbage discarding issue made by the fossil-fuel derivative determined polymers.

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6

Toward Eco-friendly Nanotechnology-based Polymers for Drug Delivery Applications

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6.1 Introduction

In recent years, pharmaceutical research has been focused on the development of nanotechnology-based drug delivery systems applicable in the field of drug delivery. Currently, the utilization of biopolymers as nanoparticles (NPs) represents a viable alternative with huge potential for the targeted distribution of drugs or biological macromolecules in the body [1]. In recent years, it was realized by the scientific community that there is a need to utilize ecofriendly nanotechnology-based polymers for formulating drug delivery systems. Their promising role and applications in the pharmaceutical research may be attributable not only to the fact that they are biodegradable and toxicologically harmless materials of low cost and relative abundance compared to their and synthetic counter parts [1, 2] but also because natural resources are renewable, and if cultivated or harvested in a sustainable manner, they can provide a constant supply of raw materials.

The use of ecofriendly biodegradable polymers has been witnessed in several studies in the past. Biopolymer-based NPs can be used efficaciously to provide bioactive molecules for *in vivo* and *in vitro* applications. Usually, nanotechnology-based drug delivery systems are an extended field of research characterized by the use of materials with sizes ranging between 1 and 1000 nm [3]. Biopolymers in pharmaceuticals are currently being used as polymeric drugs, polymer–drug conjugates, polymer–protein conjugates, polymeric micelles, and polyplexes [4]. These systems allow active principles, peptides, and proteins as well as genes to be delivered through localized release in the targeted tissues [4, 5]. The use of nanometric systems allows them to easily permeate through the cells and, therefore, leads to the targeted distribution of the agent to be delivered. The therapeutic agents after administration are usually distributed in the body by virtue of its physicochemical characteristics, but mostly through systemic circulation. To reach an effective drug concentration at the site of action, administration in high and repeated doses is necessary with some possible side effects. The utilization of biodegradable NPs is toward drug targeting, that is, the selective delivery of a therapeutic agent to its site of action independently of the mode of administration or body compartment [6]. The active therapeutic agents can be dispersed, encapsulated, or adsorbed on the surface of the NPs. Nanobiopolymers are also being utilized in the field of enzyme replacement therapy (ERT). The prospects of using NPs constituted by biocompatible and biodegradable polymers to deliver enzymes in tissues represent an enormous advantage by combating a series of ERT problems.

The use of biodegradable NPs as molecule transporters is one of the most promising strategies for controlled-release systems (CRS). The fundamental requirement for a biomaterial to be used in this sense is its biocompatibility, that is, the ability to be metabolized without any harmful effects. Systems of this type must be able to ensure characteristics such as their ability to cross the body's anatomical barriers, typically the blood–brain barrier (BBB) or the ophthalmic barrier, controlling the concentration of the drug over time and the release of the active molecule at the site of action [7].

The release of the drug from nanoparticles occurs through diffusion or with the dissociation of the NPs into monomeric molecules. This dissociation can be triggered

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7

Green-Nanotechnology-Driven Drug Delivery Systems

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7.1 Introduction

Nanoparticles (NPs) have drawn considerable interest due to their peculiar and interesting properties and applications that are beneficial over their bulk counterparts, with one or more dimensions on the order of 100 nm or less [1]. To synthesize various types of NPs, there are a large number of physical, chemical, biological, and hybrid methods available. While physical and chemical methods are more common in the synthesis of NPs, their biomedical applications, especially in clinical fields, are greatly restricted by the use of toxic chemicals. Therefore, to expand their biomedical applications, the development of reliable, nontoxic, and eco-friendly methods for the synthesis of NPs is of utmost importance. One of the options is to use microorganisms to synthesize NPs to achieve this objective [2]. In several respects, NPs produced by a biogenic enzymatic process are far superior to those particles produced by chemical methods. Although the latter methods are capable of producing large amounts of NPs with a given size and shape in a relatively short period of time, they are complex, obsolete, expensive, and inefficient, producing hazardous toxic waste that is harmful not only to the environment but also to human health. The use of expensive chemicals is eliminated through an enzymatic process, and the more acceptable "green" route is not as energy intensive as the chemical method and is also environmentally friendly [3].

Furthermore, the "biogenic" approach is reinforced by the fact that most bacteria live under atmospheric conditions of varying temperature, pH, and pressure. Because of the bacterial carrier matrix, the particles generated by these processes have higher catalytic reactivity, greater specific surface area, and improved contact between the enzyme and the metal salt in question. When microorganisms pick up target ions from their environment, NPs are biosynthesized and then transform the metal ions into the element metal through enzymes generated by cell activities [3]. In a variety of applications, biosynthesized NPs have been used, including drug carriers for targeted delivery, cancer treatment, gene therapy and DNA analysis, antibacterial agents, biosensors, reaction rate improvement, separation science, and magnetic resonance imaging (MRI). The use of the principles of green chemistry for the improved synthesis and modification of nanodrug delivery systems is discussed in this review. This is followed by a brief overview of the current research activities focusing on the biological synthesis of metallic NPs, oxide NPs, sulfide NPs, and other types of NPs, among the many papers on the synthesis and implementation of nanodrug delivery systems. The paper concludes with discussions on greener and more sustainable remediation (nano) solutions [4–6].

7.2 Unique Properties of Nanoparticles

Attention due to its unique size-dependent physical and chemical properties, the past decade has witnessed a major emphasis on NPs and -materials. Compared to bulk material, NPs show a variety of unique properties and also have unique visible properties since they are small enough to confine their electrons and create quantum effects. Because of these special properties, NPs such as gold are commonly used in diverse fields such as photonics, catalysis, electronics, and biomedicine [7]. NPs have been used to bioremediate

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13

Sustainable Nanobiocomposites

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13.1 Nanocomposites and Nanobiocomposites

In simple words, the materials that are metabolic by-products of living organisms with nanometer-scale dimensions are labeled as nanocomposite materials. These newer environment-friendly and natural nanocomposites are bio-based materials with unique structures and characteristic properties, which have recently gained significant importance from scientists worldwide. Biopolymeric-based nanocomposites are developed as unique category of materials, which are also known as "nanobiocomposites (NBCs)." These natural NBCs are potential candidates for further research and development inputs, and their wide scope of applications makes them suitable not only for biomedical science but also for in-depth research in various other fields; they also have importance from industrial perspectives. The green nanocomposites, which can also be referred as NBCs, are the next-generation sustainable materials. The nanocomposites made from renewable nanoparticles, petroleum-based materials, biopolymers, and synthetic nanofillers are considered as NBCs [1]. These types of materials are different in properties, characteristics, preparation methods, and applications. The most advantageous property of these materials is that they are biodegradable in nature. It means that these biocomposites are very safe for the environment because of their natural degradation with the help of organisms, resulting in organic by-products. Besides this, their availability in abundance in nature and also their renewable property make them the ideal candidates to replace petroleum-derived plastics and similar types of materials [2].

Interestingly, the shape of nanoparticulates plays a significant role in the development of NBCs and is also responsible for the properties shown by them. On the basis of its geometric structure, nanoparticulates are classified as nanoparticles, nanoplatelets, nanosomes, nanofibers, nanocapsules, nanotubes, nanorods, etc. The problems associated with the fabrication of nanocomposites have opened the way for the development of NBCs [3–5]. Nanoparticulates enter into the ecosystems, specifically aquatic systems, by various ways, which include industrial waste chemicals and from discharge of wastewater. These materials then undergo various climatic physical and chemical reactions and transform into several different forms. These different forms of nanoparticles can be taken up by higher organisms, and some aquatic and terrestrial organisms can also assemble these nanoparticles through various processes [6]. Finally, all these processes would result in the development of a new class of nanoparticulates known as NBCs. Increasing the usage of carbon-containing fossil resources leads to lack of these resources as their process of generation is very slow. These resources are limited in quantity and exhaustible in near future. Besides this, these types of carbon-containing materials have an impact on global environment, which creates immense problem to all living creatures on the earth [7, 8]. NBCs originated from organisms, and hence they contain a large amount of bio-based materials. They can strongly give competition to petroleum-based materials with an affordable cost performance ratio and also help in balancing strong relation between ecosystem, technology, and economy. Hence, they can be well-thought-out as green sustainable materials.

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15

Risk Assessment and Management of Occupational Exposure to Nanopesticides in Agriculture

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15.1 Introduction

15.1.1 Agriculture

The term agriculture is derived from the Latin word ager, which implies soil and cultural means cultivation. Just we can say soil cultivation. It is the science of agriculture, including work of soil cultivation, crop production, and livestock rearing. It has two main branches: Crop and animals.

Agriculture is the stepping stone in the history of the human race, due to which agriculture (farming) man settled at particular place. Agriculture has been one of human being's ancient and foremost activities. Despite the world's increasing urbanization and industrialization, nearly 50% of the work force is still involved in agriculture. Agriculture has become a major source of income in developing nations and has made a significant contribution to the country's economy.

The basic purpose of agriculture is to encourage stronger and more productive plants and crops and to develop them by enhancing the soil and water supply.

Farming is a backbone of the Indian economy. In India, about 64% of the total population depend on agriculture for their food source.

Current agriculture is heavily dependent on science and technology as well as on the physical and biological sciences. Agricultural chemistry deals with the other important agricultural issues, such as fertilizer application, insecticides and fungicides, soil quality, agriculture products analysis, and farm animal nutritional requirements.

Users demand a year-round availability of high-quality agricultural goods, but due to pests and inclement weather, there are sometimes short-term harvest fluctuations. Chemical pest controls are one way of controlling crop loss variability. In addition to reducing crop losses from pests by pesticides, there are other ways to sustain food and fiber intake.

15.2 Pesticides

Pesticides such as rodenticides, insecticides, acaricides, fungicides, herbicides, nematicides, and molluscicides are found naturally and are widely used in agriculture to increase the crop yield and productivity and generally protect plants from harmful effects such as plant diseases, insects, and weeds. There are many groups of pesticides based on application and chemistry: organochlorine pesticides, organophosphorus pesticides, carbamate pesticides, etc.

15.2.1 Understanding Pesticide Benefits

There are several types of advantages that can be related to pesticides, but the public frequently overlook these benefits. The economic advantages for farmers derived from the security of the product quality and yield and the elimination of other expensive inputs such as labor and fuel are the most evident and simplest to quantify. The rate of global pest losses for several crops in some regions found that pesticide-induced losses are much more than 50% of the achievable crop output [1]. Food production will fall without pesticides, and food prices will increase. With lower productivity and higher prices, farmers will be less

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17

Cobalt Oxide-engineered Nanomaterials for Environmental Remediation

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17.1 Introduction

Industrial development, urbanization, and population growth in short span of time resulted in numerous pollutants being produced and dumped into the atmosphere. Environmental degradation is without question one of the most critical issues which society is facing today. It is the deterioration of the atmosphere by the rapid depletion of the resources such as air, water, and soil. Biodiversity loss, habitat loss, and wild life extinction are few consequences to name resulting from environmental deterioration. Environmental remediation has come out as a necessity to save the mother earth and life on earth. It refers to employment of the techniques and habits in order to reduce the excessive exploitation of natural resources and improper disposal of the used material. Emerging innovations for remediating air, water, and soil pollutants are constantly being explored [1–6]. Remediation and reconstruction of contaminated environments are among the critical challenges tackled by the world community by means of delivering environmental sustainability for future generations. Various pollutants are responsible for the environmental degradation. For instance, extensive mining of minerals together with improper clearance of harmful by-products severely impacts the soil and water [7]. Uncontrolled use of pesticides and chemical fertilizers for exponential growth of agricultural production has perilous influence on soil and water [8]. Waste water effluent that consists of dyes, heavy metals, and organic compounds from chemical industries sternly disturbs the water bodies [9]. The most common heavy metal pollutants are arsenic, cadmium, chromium, copper, nickel, lead, and mercury which are raising concerns over the potential effects on the environment [10]. Nuclear technology which has proved to be the most efficient energy resource has also detrimentally affected the environment. The nuclear radioactive waste, radiation exposure, and accidents in nuclear reactors have potential harmful effects on the life and environment [11]. Figure 17.1 highlights various causes of contaminants polluting natural resources. In light of all the abovementioned issues that constantly challenge our environment, environmental restoration has now become a global priority. The US Market Research Report, 2020, states that the remediation and environmental clean-up services industry has grown at an annualized rate of 0.2% to $17.1 billion over the past five years [12]. This is representative of impressive developments in the production of new technologies and methods for environmental remediation and restoration.

Nanotechnology refers to the area of study and engineering that is concerned with constructing "things" on the scale of atoms and molecules – in general with size ranging in 1–100 nm. In the recent decades, nanotechnology has gained lot of attention due to the exceptional characteristics of nanomaterials. Owing to the small size, the nanoparticles offer high surface-to-volume ratio compared to their counterparts, which is beneficial for efficient adsorption of nanowaste materials [13]. Another advantage of nanomaterial is that it can be fabricated in various shapes such as sphere, rod, fiber, dots, tube, and wires, each having unique properties that help in the removal of harmful pollutants from the environment [14]. In addition to the abovementioned advantages, the surface of nanomaterials can be modified with functional groups/moieties that can

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Pharmacokinetics and Pharmacodynamics of Nanoparticulate Drug Delivery Systems

Springer

Introduction to Nanoparticulate Drug Delivery Systems

1

Jayvadan Patel, Anita Patel, Mukesh Patel, and Govind Vyas

Contents

Abstract

Nanotechnology is the innovatory technology of the twenty-first century, and nanoparticulates as drug delivery systems have created a considerable amount of attention from researchers. It is a promising interdisciplinary area of research wherever groups of atoms as well as molecules are handled at the nanometer levels. It can be defined as the systematic study of materials that have properties critically dependent on length scales on the order of nanometers. Such novel and improved properties make nanoparticulate materials promising candidates to provide the best scientific as well as technological progress in a number of fields in particular biology, communications, environment, energy, healthcare, information, medical care, and pharmacy. The use of nanotechnology in medicine and more explicitly drug delivery is set to spread speedily. The growing range of nanoparticulate-based drug delivery methods is assured of changing the formulation characteristics of new compounds and extending the lifecycle of existing compounds. In order to achieve this, the chapter deals with the definitions and classification of nanoparticulate materials, a fundamental understanding of their valuable properties, and different types of nanoparticulates employed as drug delivery systems.

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2 Nanoparticle Properties Affecting the Drug Release, Absorption, and Pharmacokinetics of Nanoparticulate Drug Delivery Systems

Prachi Pandey, Jayvadan K. Patel, and Samarth Kumar

Contents

Abstract

The nanotechnology-based drug delivery enhances the distribution and pharmacokinetic of the drug which in turn ultimately improves the efficacy of the drug. A particular advantage of nanotechnology is the ability to design and optimize the unique physiochemical properties of nanoscale materials and structures. Nanoparticle (NP) drug delivery systems have the capability to improve current disease therapies due to their ability to overcome biological barriers and release a therapeutic drug quantity in the optimal dosage range. Altering the size, shape, and/or surface chemistry of NPs allows their functionalities to be tailored to meet various needs. These factors have been observed to significantly affect the distribution and blood circulation half-life of circulating NPs by reducing the level of nonspecific uptake, delaying opsonization, and enhancing the extent of tissue-specific accumulation. Modulation of the pharmacokinetics of NPs to prevent rapid clearance from blood has been attained by tuning their sizes, and successful temporary evasion of the RES postinjection has been demonstrated by measuring blood circulation

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5 Models Used in Pharmacodynamic Evaluation of Nanoparticulate Drug Delivery Systems (NPDDS)

Megha Joshi, Chander Parkash Dora, Lokesh Kaushik, Jayvadan Patel, and Kaisar Raza

Contents

Abstract

Pharmacodynamic models are an essential tool in clinical pharmacology for the prediction of safety and efficacy of drug molecule using the in vitro and in vivo data available from the previous studies. These models are based on the mathematical equations and are helpful in the development of new drugs and dosage forms as there were numerous difficulties associated with conducting the clinical trials like cost, ethical issues, and adverse effects related to the study. The common types of pharmacodynamic models covered under this chapter are direct and indirect effect models. The direct model includes fixed effect model, linear model, log-linear model, E_{max} model, and sigmoid E_{max} model. The basic requirements for developing these models are the appropriate software and the expert analysts to develop and analyze the model. Currently, most of the drugs coming out of the pharmaceutical industry exhibit the issue of low solubility and insufficient bioavailability. Nanoparticulate drug delivery systems (NPDDS) are a newer approach for solving these problems of drug molecules. For speeding up the development of nanoformulations, pharmacodynamic models are also utilized. These models are utilized in the development of nanoparticles, liposomes, and nanogel. However, there is very less work done in utilizing the pharmacodynamic models in the development of NPDDS. Hence, there is a growing need in utilizing these models in the development of NPDDS to save the cost and time.

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6 Preclinical Animal Models for the Experimental Design of Pharmacokinetic Studies with Nanoparticulate Drug Delivery Systems

Aaishwarya Deshmukh, Jayvadan K. Patel, and Yashwant V. Pathak

Contents

Abstract

A comprehensive investigation of disposition and pharmacokinetic (PK) behaviours is a dire step in the translation of nanomaterial studies from preclinical animal studies to humans. Disposition and PK data are exploited to evaluate the systemic exposure and effects of nanomaterials which are principal contributing factor of the potential toxicity and therapeutic efficacy of nanoparticulate drug delivery systems (NPDDS). NPDDS exhibits an exceptional challenge for investigations pertaining to disposition and PK due to their extended circulation times, nonlinear PK profiles and broad distribution patterns. Studies are lacking for predicting and extrapolating associations between nanomaterial physicochemical properties and their in vivo behaviours and further are bewildered by various differences in the context to anatomy, physiology and immunology amongst preclinical animal models and clinical settings. Imprecise assumptions of disposition, PK and toxicoki-

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8 Pharmacokinetics and Pharmacodynamics of Liposomal Nanoparticles

Prachi Pandey, Jayvadan Patel, Samarth Kumar, and Yashwant Pathak

Contents

Abstract

In the past few years, some major advancements in liposome technology have induced the rapid development of new pharmaceutical liposomal applications. For the purpose of optimizing the delivery of factors for maximum efficacy, novel methods have been proposed to increase the permeation rate of drugs temporarily and deliver the desired target compound in a time-regulated and locally restricted manner to the target site.

Lipid-based nanoparticles (LNPs) are promising delivery vectors in the treatment of cancer, inflammation, and infections and are already used in clinical practice. Numerous strategies based on LNPs are being developed to carry drugs into specific target sites. The common purpose for all of these LNP-based platforms is to improve the payload's pharmacokinetics, biodistribution, stability, and therapeutic benefits and also to reduce adverse effects to a minimum. In addition, the delivery

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9 Pharmacokinetics of Drug-in-Polymer Matrix-Based Nanoparticulate Drug Delivery System

Sopan Nangare, Prashant Patil, Ashwini Patil, Prashant Deshmukh, Trupti Powar, Jidnyasa Pantwalawalkar, Zamir Khan, Rahul Tade, Jayvadan K. Patel, and Pravin Patil

Contents

Abstract

The application of nanotechnology in drug delivery is gaining much attention from researchers due to their plethora of benefits especially in the improvement of pharmacokinetics as compared to conventionally available dosage forms. In this line, numerous advanced approaches have been adopted that demonstrated excellent applicability in the drug delivery systems. Despite this, they are lacking the foremost limitations related to absorption, distribution, metabolism, and excretion of the drug that affect the therapeutics of the active. Noteworthily, polymeric materials

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11 Metallic Gold Nanoparticles: In Vivo Pharmacokinetics and X-Ray Contrast Imaging Studies

Nishith Patel, Sunita Chaudhary, and Jayvadan K. Patel

Contents

Abstract

Among all metal nanoparticles, gold nanoparticle has emerged as a better drug delivery system, with higher efficiency and less side effects due to its unique physical, chemical, optical, and electrical properties, higher dug loading, and target transportation of drug. Due to its unique fluorescent quenching, surface-enhanced Raman spectroscopy, surface plasmon resonance properties, good binding capacity, and tunable property, gold nanoparticles have been widely used in target therapy, in vivo molecule imaging, and various sensor and molecular probe manufacturing. The most commonly used approaches for the formulation of gold nanoparticles are categorized as physical, chemical, and biological approaches. Controlling gold nanoparticles' size, shape, and morphology plays a critical role in its in vitro analysis, pharmacokinetic study, and biomedical application. In vivo, the pharmacokinetics of gold nanoparticle depends on particle size, shape, surface charge, surface modification, and route of exposure. The generally used animal models for the pharmacokinetic studies of gold nanoparticle are rat and mice. Before checking for its pharmacokinetic study, it has to be analyzed for various in vitro studies using different analytical techniques. Gold nanoparticles act as potential X-ray contrast imaging agents with potent X-ray absorption, low toxicity with potential biocompatibility, and high absorption coefficient.

Keywords

Gold nanoparticle · Pharmacokinetic study · X-ray contrast imaging

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12 Mucoadhesive Nanoparticulate Drug Delivery System (NPDDS): In Vitro and Pharmacokinetic Studies

Sanjay Patil, Bhavin Choradiya, and Jayvadan Patel

Contents

Abstract

The nanocarriers approach is currently focused on the delivery of drugs or active agents to the site of action in an appropriate concentration. Entrapment of drug within nanocarriers may radically transform their bioavailability and tissue distribution profiles. These changes can augment the site-specific delivery with reduced side effects. Therefore, nanoparticles can improve the therapeutic efficiency and are excellent carriers. The mucoadhesive nanoparticles are used to prolong the residence time and bioavailability of the entrapped drug in mucous membrane. In the last couple of decades, several methods have been developed to prepare mucoadhesive nanoparticles. The various in vitro characterization parameters used for evaluation of mucoadhesive nanoparticles are size, zeta potential, encapsulation efficiency, mucoadhesion studies, transmission electron microscopy, differential scanning calorimetry, Fourier-transform infrared spectroscopy, x-ray diffraction, in vitro drug release, in vitro assays like cytotoxicity studies, etc. Ocular pharmacokinetics is an evaluation of absorption of drug corresponding to time and quantity of administered medications. Quantity of drugs change in tissues or fluids of the eye when it is given in different concentrations through various dosage forms. Ocular pharmacokinetics is oftentimes performed by a multi-compartment model, expecting a homogeneous circulation of drugs in every eye tissue. In view of this, present chapter

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13 Pharmacokinetic and Tissue Distribution Study of Solid Lipid Nanoparticles

Himanshu P. Paliwal, Bhupendra G. Prajapati, Dignesh Khunt, Chilakapalli Shirisha, Jayvadan K. Patel, and Yashwant V. Pathak

Contents

Abstract

In recent times, the development of therapeutic products by using nanoparticle technology has given rise to progressive increment in a number of investigations based on improvement of solubility, penetrability, stability, etc. Solid lipid nanoparticles (SLN) involve absorption and localization through transcellular and paracellular mechanism which is one of the advanced nanoparticle-based formulations of the low solubility of drugs. This chapter entails the outline of the vital features of solid lipid nanoparticles and describes the pharmacokinetic and distribution outcomes of the SLN formulation designed for various routes. The key benefits of using such a nanocarrier in specific therapeutic circumstances and to resolve production and delivery issues are discussed. The major portion covers the explanation on pharmacokinetic studies

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14 Factors Affecting the Clearance and Biodistribution of Polymeric Nanoparticles

Komal Parmar, Jayvadan Patel, and Yashwant Pathak

Contents

Abstract

Nanoparticles are promising drug delivery for various therapeutic applications. Pharmacokinetics is important to study the in vivo fate of nanoparticles. Biodistribution and clearance are the important parameters of pharmacokinetics to be considered. Impact of various characteristics of polymeric nanoparticles affects biodistribution and clearance of nanoparticles. The chapter focuses on four important characteristics of polymeric nanoparticles affecting their biodistribution and clearance.

Keywords

Clearance · Biodistribution · Polymeric nanoparticles

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1 Introduction

Nanodelivery systems are a comparatively new but quickly emerging field in which nanoscale materials are used as diagnostic tools or to administer therapeutic medicines to precise targets in a controlled mode [30, 57, 82, 84]. Nanoparticles can be turned into intelligent devices, encapsulating medicinal and imaging chemicals while also having stealth properties, by manipulating their size, surface features, and composition [69]. They are intended to alter the biodistribution and pharmacokinetics of the drugs, allowing for a higher dose to be delivered to a targeted disease tissue, in order to improve the therapeutic efficacy and render reduced toxicity. Many different materials and shapes of nanoparticles have been

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Clearance Pathways and Tumor Targeting of Imaging Nanoparticles for Diagnostics

17

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Contents

Abstract

Nanotechnology provides numerous opportunities in the early detection of cancers and helps to reduce cancer-related mortality. Nanoparticles with diverse and tunable properties represent a promising strategy for molecular imaging. Nanoparticle-based imaging agents have a great potential to provide enhanced sensitivity and specificity for tumor imaging. However, their prolonged tissue retention and potential toxicities have resulted in their restricted clinical translation to date. In the present compilation, clearance pathway and tumor targeting of imaging nanoparticles are summarized. The impact of size, shape, surface modification, and surface charge of NPs on their clearance is discussed. Tumor targeting strategies, i.e., active and passive targeting, are also described in the present compilation.

Keywords

Nanoparticles · Diagnosis · Cancer · Clearance · Tumor targeting · EPR effect

Abbreviations

AuNPs	Gold nanoparticles
CD-1 mice	Originated from Swiss mice

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Pharmacokinetics of Nanoparticle Systems for Pulmonary Delivery

19

Bhupendra Prajapati, Himanshu Paliwal, and Jayvadan Patel

Contents

Abstract

The introduction of nanotechnology in the pharmaceutical field has incited the attention of researchers to develop nanoparticle-based formulations to treat pulmonary diseases. The main reason behind this popularity is because of the vast surface area of the lungs and limited barriers obstructing the penetration. The nanoparticle drug delivery systems targeting the lungs by inhalational route provides potential alternative to oral and intravenous systems of drug delivery as it not only prevents the inactivity by enzymatic degradation and first-pass metabolism, but it also restricts the undesirable adverse effects. In case of pulmonary diseases, inhalational systems furnish targeted delivery to improve therapeutic efficiency at the specific site. The pulmonary systems have been fabricated using a variety of methods, ranging from traditional approaches like spray-drying and pulverization to the advanced techniques, such as supercritical fluid extraction, micellar solubilization, etc. In order to assess the efficacy and targetability, the pharmacokinetic and biodistribution studies of nanoparticle formulations for pulmonary delivery are very essential. The chapter aims at discussing about various nanoparticle formulations which have been developed specifically for targeting the lungs. A number of recent and relevant literatures with the outcomes of their pharmacokinetic and biodistribution studies have been talked about and compared to justify the potential of nanoparticle formulations for the management of pulmonary diseases.

Keywords

Pulmonary delivery · Nanoparticle formulation · Inhalational route · Pulmonary diseases · Pharmacokinetic studies · Biodistribution

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In Vivo Biodistribution and Pharmacokinetic Studies of NPDDS for Brain Targeting

20

Aaishwarya Deshmukh, Jayvadan Patel, Govind Vyas, and Mukesh Patel

Contents

Abstract

Central nervous system (CNS) diseases have become distressing to humankind due to multiple reasons, lifestyle changes, and unrelenting decline in the environment being the major contributing factors. Since the blood-brain barrier (BBB) and blood-cerebrospinal fluid barrier (BCSFB) are the chief physiological barriers that hold a large logjam for the efficacious treatment of CNS disorders as well as brain tumours, complex anatomical architecture, exclusive microenvironment, and discrimination for any and every foreign material including drug as well can be considered as the leading challenges for delivery of drug to the CNS. Lately, it has become a necessity to develop upright cargo, which carts drug to the CNS in concentrations not only effective but also without triggering systemic side effects. Nanoparticulate drug delivery systems (NPDDSs) have been associated to discourse the difficulties associated with treatment of neurological disorders and have proven cutting edge over the conservative CNS-related

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Nanoparticle Pharmacokinetic Profiling In Vivo Using Magnetic Resonance Imaging

22

Bhupendra G. Prajapati, Himanshu P. Patel, and Jayvadan K. Patel

Contents

Abstract

The rapid progression in the field of nanotechnology has given rise to production of nanoparticles for in vivo imaging and targeted delivery. A number of novel nanoparticles may suffer from inadequate activity due to unwanted tissue localization or inappropriate low half-lives. Pharmacokinetic profiling can assist in deriving ideas about the size of the particle, surface coating, associated moieties, etc. which can aid in resolving the undesirable outcomes. The utilization of imaging techniques such as magnetic resonance imaging (MRI) may play vital role in studying the pharmacokinetics and biodistribution of drugs or drug carriers for the treatment of several diseases. Along with the generation of anatomical images, MRI can also serve to target and quantify the radioactive or optical probe labelled nanocarriers for delivery of theranostics. The in vivo studies using MR-active nanoparticles will help in deciphering the behaviour of the synthesized nanoparticles inside the body to understand their distribution and elimination. This chapter will comprehensively focus on recent and relevant literatures and their useful outcomes with regard to drug release studies, pharmacokinetics studies, or biodistribution studies by using MRI contrast agents.

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