Jayvadan K. Patel
YashwantV.Pathak*Editors*

Emerging Technologies for Nanoparticle Manufacturing

Springer

1 Introduction to Nanomaterials andNanotechnology

JayvadanK.Patel,AnitaPatel,andDeepakBhatia

Abstract

Nanotechnologyistheinnovatorytechnology of the twenty-first century, and nanoscale materialshavecreatedaconsiderableamount of attention from researchers. It is an emerginginterdisciplinaryareaofresearchwherever groupings 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 lengthscalesontheorderofnanometers.Such novelandimprovedpropertiesmakenanoscale materialspromisingcandidatestoprovidethe best scientific as well as technological progress in a number of fields in particular communications,electronics,energy,environment, information, biology, pharmacy, health care, and medical care. This chapter first draws attention to the different definitions and classificationofnanomaterialsbasedontheirorigin, chemical composition, materials, and their dimensions.The fundamental properties of matter transform at the nanoscale and the most enhanced and valuable properties of manufacturednanomaterialssuchasconfinement effects, surface effects, mechanical properties,structuralproperties,thermalproperties, optical properties, and magnetic properties are also described. In the last section, we have discussed various methods to fabricate nanomaterials.

Keywords

Nanoscale materials · Size-dependent characteristics·Distinctiveproperties· Superior performance

1 Introduction

The first technological revolution, at the end of the eighteenth century, has sparked the advancement of industrial research and the attainment of novel materials (Fajardo et al. 2015).At present, theobstaclesaretheminiaturizationofdevicesas well as instruments; lesser volume, lesser power consumption but superior performance. The progressreliesuponsearchingoutnovelpleasing materialsandthecapacitytocreateminutestructures with high accuracy. Though, the growth is not so smooth and effortless. One of the best splendid techniques created to answer such a conditionisnanotechnology(Fajardoetal.2015; Huyen2011). Recently, the study engaging nanoscalematerialshascreatedaconsiderable

J.K.Patel(✉)·A.Patel
NootanPharmacyCollege,SankalchandPatel University, Visnagar, Gujarat, India

D. Bhatia
ShenandoahUniversity–ICPHFairfax,Bernard J.DunnSchoolofPharmacy,Fairfax,VA,USA

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2 Biomedical Applications of Nanoparticles

Manish P. Patel and Jayvadan K. Patel

Abstract

During the last decade, biomedical applications of nanoparticles describes the most interesting and investigated applications of nanoparticles, emphasising their therapeutic impact. There have been enormous developments in utilising the power of nanotechnology in various fields including biomedical sciences. The most important biomedical applications of nanoparticles are in disease diagnosis and treatment. Functionalised nanoparticles possess unique properties as contrast agents for dual and even triple modal imaging. The potential of these new generation nanoparticles in targeted drug delivery has revolutionised safe and effective pharmacotherapies for complex diseases. One more step ahead, theranostic nanoparticles are equipped with dual capabilities for disease diagnosis as well as treatment. Specifically, designed nanoparticles have also been utilised to improve the delivery and efficiency of different vaccines, including their application in cancer immunotherapy. This chapter provides an overview of the biomedical applications of nanoparticles and recent advancements in this area on the basis of current research. Progress made in the therapy of severe diseases, such as cancer and difficult infections, is strictly correlated to the scientific progress and technological development in the field of materials science. Nanoparticles have numerous therapeutic applications, starting with the design of new drugs, delivery systems, therapeutic materials, and their contribution to the development of preventive strategies. The chapter highlights the impact of nanoparticles on the therapy of infections, antimicrobial effect, and also anticancer strategies. Nanoparticles are minute particles that produce a major change in the healthcare and biomedical industry. It is not restricted to any field and its presence is observed in every field of biomedicine from diagnosis to treatment to implants to cosmetics.

Keywords

Molecular biology · Biochemistry · Drug targeting · Diagnosis · Cell biology · Biological engineering

M.P. Patel (✉)
Department of Pharmaceutics and Pharmaceutical Technology, L. M. College of Pharmacy, Ahmedabad, India

J.K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

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Nanocrystallization andNanoprecipitation Technologies

VivekP.Patel,DharaV.Patel,andJayvadanK.Patel

Abstract

In the last few years, nanoparticles and their applications have dramatically diverted science in the direction of a brand new philosophy. Nanoparticles are building the bridge of scientific knowledge connecting bulk materials to atomic or molecular structures. In the present scenario, nanoparticle research is a very promising branch of scientific research owing to the wide range of potential and promisingapplicationsespeciallyinbiomedical, optical and electronic fields.

Inthecurrentpharmaceuticaldevelopment pipeline,thepoorwatersolubilityofdrugcandidatesremainsthebiggestchallenge.Various processeshavebeendevelopedtoincreasethe solubility, dissolution velocity and bioavailabilityoftheseactiveingredientsbelongingto the biopharmaceutical classification system (BCS)IIandIVclassifications.Nanocrystal delivery is an emerging technique for overcoming the limitations of drugs that dissolve poorlyinwater.Nanocrystalsareproducedin the form of nanosuspensions using top-down (e.g., wet milling) and bottom-up methods (e.g., antisolvent precipitation) in FDA-approveddrugproducts.Anultracryo-milling technique using liquid nitrogen and dry ice beadshasbeenusedasanovelcontamination-freeprocess.Inthecaseoftheantisolventprecipitation technique, ultrasound and rapid mixingdeviceshavebeenusedasnewprocess intensification techniques. Technological advancementsinmillingaswellasantsolvent precipitation now enable the production of drugnanoparticlesonacommercialscalewith relative ease.

Thischapterprovidesanupdatedreviewof nanocrystal techniques along with marketed product evaluations and a survey of the commercially relevant scientific literature.

Keywords

Nanoparticles · Nanocrystallization · Nanomilling·Antisolventprecipitation

V. P. Patel (✉)
SunPharmaceuticalIndustriesLtd,
Vadodara,Gujarat,India
e-mail:vivek.patel@sunpharma.com

D.V.Patel
PioneerPharmacyDegreeCollege,
Vadodara, Gujarat, India

J.K.Patel
Nootan Pharmacy College,
Sankalchand Patel University,
Visnagar, Gujarat, India

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5 Production of Nanocomposites via Extrusion Techniques

Komal Parmar, Jayvadan K. Patel, and Deepak Bhatia

Abstract

Nanomaterials have always attracted the world with their innumerable and fascinating properties. Incorporation of nanoparticles in the nano matrix makes the nanocomposite which further shows amelioration in the basic characteristics of the material. The present chapter reviews the extrusion method employed in the fabrication of various types of nanocomposites including polymer matrix and metal matrix systems.

Keywords

Nanocomposites, · Polymer matrix · Matrix systems · Extrusion

1 Introduction

Dimensions of the particle play an important role in the physico-chemical properties of the matter. Nano-scale dimensions may lead to change in the properties of the material which can thereby prove to be beneficial in wide areas of science such as biomedical science (Ramos et al. 2017), electronics (Kamyshny and Magdassi 2019), optics (Ren et al. 2019), electrochemistry (Rassaei et al. 2011) and food science (Singh et al. 2017). Nanocomposites are the heteroge- neous material of one or more nanoparticles embedded in a matrix. Depending on the compo- sition of matrix, nanocomposites are classified into three types, viz., Ceramic-based nanocom- posites, metal-based nanocomposites and polymer-based nanocomposites (Fig. 5.1). Their properties are determined by composition, struc- ture and interfacial interactions of the materials. Ceramic-based nanocomposites are fabricated by various methods including polymer precursor process (Yue et al. 2019; Lue et al. 2016), sintering method (Wen et al. 2018; Kuznetsova et al. 2018). Metal matrix nanocomposites are pro- cessed by techniques namely spray pyrolysis (Zheng et al. 2017; Zhao et al. 2012), rapid solid- ification (Sobhani et al. 2013; Nayak et al. 2012), vapor phase synthesis (Muflikhun et al. 2019; Vucaj et al. 2014), electrodeposition method (Beltowska-Lehman et al. 2018; Birlik et al. 2016), sol-gel method (Famojuro et al. 2013; Sui

K. Parmar (✉)
ROFEL, Shri G. M. Bilakhia College of Pharmacy, Vapi, Gujarat, India

J. K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

D. Bhatia
Shenandoah University – ICPH Fairfax, Bernard J. Dunn School of Pharmacy, Fairfax, VA, USA

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6 The Use of Supercritical Fluid TechnologiesforNanoparticle Production

JayvadanK.Patel,DeepakBhatia,
YashwantV.Pathak,andAnitaPatel

Abstract

One of the most important challenges that pharmaceutical companies are presently facing is low bioavailability of drug, which is generally a result of poor aqueous drug solubility/dissolution rates; this may restrict the therapeuticefficiencyofmarketeddrugs.The bioavailabilityofpharmaceuticals'existingin asolidformulationstronglyreliesonthesize, particle size distribution, and morphology of the particles. In recent years, the major approachesthathavebeenputintopracticeto overcome poor drug solubility/dissolution rates are drug particle size reduction (i.e., micronization/nanonization). Numerous particleengineeringtechniqueshavebeenapplied for this purpose, including spray-drying, freeze-drying, liquid anti-solvent crystallization or milling processes. These technologies presentnumerousdrawbacks,forexample,the difficulty of controlling particle size and particlesizedistribution,productdegradationdue to mechanical or thermal stresses, or the contamination of the particles with organic solvents or other toxic substances. Therefore, different alternative precipitation techniques are being explored. In recent years pharmaceutical processing using supercritical fluids, for the precipitation of pharmaceuticals and natural substances, has attracted great attentionfromthepharmaceuticalindustry.Thisis mostly attributable to the some well-known beneficial technological features of this method, as well as to other increasingly important subjects for the pharmaceutical industry, namely, their "green" sustainable, safe, and "environmentally friendly" intrinsic characteristics.

Keywords

Supercritical fluid · Particle formation · Nanoparticles·Environmentallyfriendly

1 Introduction

Thebioavailabilityofpharmaceuticalsexistingin a solid formulation strongly relies on the size, particle size distribution, and morphology of the particles. The particle precipitation into micro/nanoparticleshasbeenanactiveresearchareafor decades(ChattopadhyayandGupta2001a;

J.K.Patel·A.Patel (✉)
NootanPharmacyCollege,SankalchandPatel University, Visnagar, Gujarat, India

D. Bhatia
BernardJ.DunnSchoolofPharmacy,Shenandoah University – ICPH Fairfax, Fairfax, VA, USA

Y.V.Pathak
CollegeofPharmacy,UniversityofSouthFlorida Health, Tampa, FL, USA

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11 High-Pressure Homogenization Techniques for Nanoparticles

Preksha Vinchhi, Jayvadan K. Patel, and Mayur M. Patel

Abstract

High-pressure homogenization (HPH) has been employed for unit operations like comminution, mixing, and stabilization of pharmaceutical solids and nanoparticles. With advancing nanotechnology, the HPH technique has undergone discernible evolution and has broadened the scope of its pharmaceutical applications by facilitating particle engineering. An in-depth understanding of fluid dynamics has helped the researchers devise innovative designs for high-pressure homogenizers with higher processing capacity and efficiency. The present chapter provides useful insights on the fundamentals involved in the process of HPH of colloidal dispersions, basic instrumentation of homogenizers, and theories on forces involved in homogenization. HPH has the distinct advantage of being one of the most versatile and scalable processing methods for the preparation of different vesicular and non-vesicular lipid-based nanosystems such as nanoemulsions, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), nanocrystals, as well as polymeric nanoparticles. The chapter has summarized the effect of various processing and product variables on characteristics of the aforementioned nanoparticle formulations. The chapter provides a comprehensive overview of the processing attributes of HPH that may facilitate the development of nanoparticles to attain desirable pharmaceutical attributes.

Keywords

Nanoparticles · Particle engineering · Homogenization pressure · Homogenization cycles · Fragmentation and disruption

1 Introduction

The concept of homogeneity and heterogeneity is derived on the basis of uniformity in a substance or a system, wherein the homogeneity signifies uniformity in a character or composition, while heterogeneity designates nonuniformity. The applicability of these notions is possible at a diverse level of intricacy from atoms or molecules to galaxies. The term "homogenization" denotes "to render uniformity throughout in terms of structure, composition, and character." Homogenizing is an umbrella word depicting multiple unit operations like mixing, blending,

P. Vinchhi · M. M. Patel (✉)
Department of Pharmaceutics, Institute of Pharmacy, Nirma University, Ahmedabad, Gujarat, India

J. K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

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Solvent Emulsification Evaporation and Solvent Emulsification Diffusion Techniques for Nanoparticles

Sunita A. Chaudhary, Dasharath M. Patel, Jayvadan K. Patel, and Deepa H. Patel

Abstract

Nowadays, there has been an increased demand of nanoparticulate-based drug delivery as nanoparticles (NPs) generally give more advantages over the conventional drug carriers for targeting in various parameters like more drug encapsulation, more stability and site specificity, sustained release profile and the ability to deliver both lyophilic and lyophobic types of drug particles using differ- ent modes of administration. Nanocarriers have been expansively studied as particulate drug delivery in the field of pharmaceuticals, due to their controlled and sustained release properties, small size and biocompatibility with body tissues. Manufacturing technique used to prepare nanoparticles plays a vital role in achieving their desired properties for a particular application. Several methods to formulate nanoparticles have been developed during the last many decades, and these are classified based on whether the particle formation undergoes a polymerization reaction or a nanoparticle forms directly from a preformed polymer or ionic gelation method. The choice of method for the preparation of nanoparticle is highly dependent on the physicochemical properties of both the polymer and the drug compound. Polymeric nanoparticles are generally manufactured by polymerization of monomers using anionic polymer or by preparing homogeneous dispersion of the dissolved polymers which gives nanoparticles using various methods such as solvent evaporation, emulsification solvent diffusion, salting out, emulsification diffusion and supercritical fluid (SCF) technology. This chapter emphasizes on how emulsification followed by solvent evaporation and solvent diffusion permits an emulsion of a polymer solution to customize as nanoparticles. The chapter also provides concise information on recent trends of research in specified domain.

Keywords

Nanoparticles · Emulsification solvent evaporation · Emulsification solvent diffusion

S.A, Chaudhary (✉)
Arihant School of Pharmacy & Bio Research Institute, Gandhinagar, Gujarat, India

D.M. Patel
Graduate School of Pharmacy, Gujarat Technological University, Ahmedabad, Gujarat, India

J.K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

D.H. Patel
Parul Institute of Pharmacy and Research, Faculty of Pharmacy, Parul University, Vadodara, India

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Membrane Techniques for the Preparation of Nanomaterials

Komal Parmar, Jayvadan K. Patel, and Deepak Bhatia

Abstract

Nanomaterials are always in demand owing to its wide variety of applications in various fields of science. Various methods are avail- able for the synthesis of nanomaterials, but membrane techniques proved to be efficient in the preparation of nanoparticles. The present chapter reviews the membrane techniques reported in the fabrication of various types of nanomaterials such as nanowires, nanorods, nanospheres, and others.

Keywords

Membrane · Techniques · Nanomaterials · Template

K. Parmar (✉)
ROFEL, Shri G. M. Bilakhia College of Pharmacy, Vapi, Gujarat, India

J. K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

D. Bhatia
Shenandoah University – ICPH Fairfax, Bernard J. Dunn School of Pharmacy, Fairfax, VA, USA

1 Introduction

Nowadays terms like "nanoscience" and "nanotechnology" are not only limited to the research field but also used in day to day life. The applied science involves the technology at nanoscale, which is about 1–100 nanometers. Nanomaterials are used in wide array of science including electronics (Kamyshny and Magdassi 2019), optics (Shen et al. 2000), composite materials (Sahayet al. 2014), energy storage (Liu et al. 2017), electrochemistry (Li et al. 2009), food science (Singh et al. 2017), and health science (Chen et al. 2013). Nanomaterials are nanotechproduct designed to be very small with unique physical and chemical characteristics that prevails at nanoscale. The physical and chemical properties at nanoscale are largely varied than their large-scale version, which can prove to be beneficial. For instance, nanoscale particles are reported to cross the complex blood-brain barrier, which can further host for targeted health benefits (Saraiva et al. 2016; Thomsen et al. 2015). Thus, since the discovery of nanomaterials, a deep interest has been developed for these nano-objects, and extensive research has been done. These nano-objects with their large surface area show trenchant thermal, mechanical, optical, electronic, and chemical properties as compared to its bulk counterpart. This unique characteristic is developed due to the quantum size of the material (Roduner 2006). The nanomaterials can be clas-

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Manufacturing Techniques for Carbon Nanotubes, Gold Nanoparticles, and Silver Nanoparticles

Tejal Mehta, Renuka Mishra, Chintan Pansara, Chetan Dhal, Namdev Dhas, Kartik Hariharan, and Jayvadan K. Patel

Abstract

Extensive research has been focused around organic and inorganic nanoparticles (NP) due to their unique and abundant benefits such as superior drug loading, biocompatibility, and role in drug delivery, biosensing, and theranostic. Among the organic NPs, carbon nanotubes (CNT), graphene NP, and fullerenes are widely explored, while gold and silver are extensively used for inorganic NP in biomedicine. The fabrication of CNT and its types like single-walled CNT (SWCNT) and double-walled CNT using conventional methods like arc discharge method, laser ablation, and chemical vapor deposition has been considered in detail. The traditional method of preparation of gold NPs (GNPs) is chemical reduction method which uses toxic chemicals or yields by-products which may compromise its inert characteristic. Thus, the current trend has been shifted toward the synthesis of GNPs using green method. In the last few decades, incredible innovations have come up regarding the applications and methods of fabrication of silver nanoparticles (AgNPs). Similar to methods used for the fabrication of GNPs, AgNPs are also manufactured by various chemical methods such as reduction, light-mediated ion implant. The additional method which has been extensively explored is green synthesis of AgNPs using plants, bacteria, and fungi. This chapter provides an insight into the commonly used techniques as well as recently explored techniques in preparation of carbon nanotubes, gold NPs (GNP), and AgNPs.

Keywords

Manufacturing · Carbon nanotubes · Single- walled carbon nanotubes (SWCNT) · Gold nanoparticles · Silver nanoparticles · Green synthesis · Chemical synthesis

1 Introduction

Carbon nanotubes (CNTs) are relatively new nanomaterials known to the public for nearly 20 years; however, their history is somewhat longer. CNTs were first discovered and identified by Radushkevich and Lukyanovich in 1952 (Radushkevich and Lukyanovich 1952) and then

T. Mehta (✉) · R. Mishra · C. Pansara · C. Dhal
N. Dhas · K. Hariharan
Department of Pharmaceutics, Institute of Pharmacy, Nirma University, Ahmedabad, Gujarat, India
e-mail: tejal.shah@nirmauni.ac.in

J.K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

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Nanomedicine Scale-Up Technologies: Feasibilities and Challenges

Dasharath M. Patel, Nitesh N. Patel, and Jayvadan K. Patel

Abstract

Size, shape, morphology, size distribution, targetability, and functionality of developed nanoparticles are the key parameters for their effective biomedical applications. Such desired characteristics should be reproducible and scalable. The production of nanoparticles is a challenging task in terms of reproducibility of size and monodispersity. Desired reproducible drug release profile from nanoparticles is required to further establish batch-to-batch uniformity and quality performance by in vitro in vivo correlation performance. The method of nanoparticle production depends on many factors including intention of application, material used for preparation, nature of bioactive to be loaded, etc. The suitable selection of materials and appropriate method of production of nanodevices is required because the in vitro and in vivo performances of the systems depend on the material characteristics as well as the production method. The preparation methods that require the use of organic solvents and the removal of residual solvents from the final product can often be tedious. The regulatory guidelines require the manufacturers to ensure the purity and safety of the final nanoparticle-based formulations. Numerous methods have been developed in order to produce nanoparticles of desired characteristics. Emerging methods such as membrane extrusion, supercritical fluid technology, and microfluidizer technology have scale-up capabilities with few products of these technologies in the market. However, application of these methods for developing targeted and surface functionalized nanoparticles at large scale is still debatable. This chapter summarizes an overview of nanoparticle production methods, scale-up issues highlighting industrial applicability, and challenges associated with their successful application as clinical nanomedicine.

Keywords

Nanoparticles · Scale-up · Challenges · Drug delivery · Drug targeting

D.M. Patel (✉)
Graduate School of Pharmacy, Gujarat Technological University, Ahmedabad, Gujarat, India

N.N. Patel
Formulation Development, Emcure Pharmaceuticals Limited, Adalaj, Gujarat, India

J.K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

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Patent Survey on Recent TechnologyforNanoparticles

ManishP.PatelandJayvadanK.Patel

Abstract

Apatentisaformofrightgrantedbythegovernment to an inventor, giving the owner the right to exclude others from making, using, selling, offering to sell, and importing an invention for a limited period of time, in exchange for the public disclosure of the invention.Aninventiongenerallyhastofulfill threemainrequirements:ithastobenew,not obvious, and have an industrial application. The chapter represents patent distribution according to the different types of nanoparticles used as well as the patent distribution accordingtotheresponsestodifferentstimuli; the highest responses tend to fall under the receptor-/aptamer-mediated category. Receptors/aptamers are used as an attractive strategy to enhance the therapeutic index of drugs and to specifically deliver these agents to the defined target cells, thus keeping them away from healthy cells, which are sensitive to the toxic effects of the drugs. The chapter alsofocusesonpatentdistributionaccording totheroutesofadministrationofthedrugparticle;themostcommonlyusedrouteisparenteral, owing to the fact that the effects of the medication are much rapid and that it can be administered directly to the site. Also discussedisthepatentdistributiononthebasisof form of delivery. Earlier known as lipid vesicles,therecentmostpopularformofdelivery of the drugs are liposomes, as is evident from thegraph.Theexceptionallyhighuseoflipoposomesaccountstothefactthattheyhavehigh retention rates and excellent targeted sustained release. The patent distribution trends relate the five broad classifications of cancer types. Most widely treated cancer is carcinoma, which contributes the highest ratio of patentsasanalyzed.Carcinomaclassincludes themostcommontypeofcancersoccurringin humans and can be cured using the technology implying nanoparticles, while sarcoma cancers, related to bone and the connective tissues,isaverycomplexcategoryandisdifficult to treat using any technique

Keywords

Nanocrystals·Drugdelivery·Routeof administration · Cancer · Computed tomography

M.P.Patel(✉)
LMCollegeofPharmacy,Ahmedabad,India

J.K.Patel
NootanPharmacyCollege,SankalchandPatel University, Visnagar, Gujarat, India

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Current Challenges and Future Directions in Nanomedicine

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Snigdha Das Mandal, Surjyanarayan Mandal, Yashwant V. Pathak, and Jayvadan K. Patel

Abstract

Nanomedicine research describes the medical application of nanotechnology and nanoparticle-based drug delivery systems for the treatment of cancer over the past two decades. Nanomedicine is basically a product of a newer scientific technology known as nanotechnology. Nanotechnology is a multidisciplinary scientific field that transforms the pattern of detecting diseases in the human body and also treating the damage. Nanomedicine applies to highly specific medical involvements for the prevention, diagnosis and treatment of various diseases. This developing discipline of nanomedicine brings active pharmaceutical agent and nanotechnology together in order to alter the therapies as well as improve the existing treatment procedures. These nanomedicines are capable of overcoming the biological barriers in the human body to improve the way to deliver the incorporated drug compounds to specific tissues and organs at a predetermined rate. More precisely, nanomedicines have been observed to modify the cellular and tissue uptake of therapeutic compounds and hence improve the biodistribution of compounds to target sites in vivo. In nanomedicine, the active biomolecules and their formulations are manipulated to produce nanostructures of pharmaceuticals of the same size so as to produce predetermined beneficial effect in human beings. These nanomedicines produce an excellent solution for early non-faulty diagnosis of diseases and hence will enhance the treatment of cancer, diabetes, Alzheimer's, Parkinson's and cardiovascular diseases. Nanomedicines have demonstrated several significant therapeutic advantages of biomolecules, however the beneficial clinical translation of these nanotechnology-based biomolecules have not progressed as expected. Hence, in this chapter, current understanding of nanoformulations of bioactives has been exemplified and the challenges are being addressed.

Keywords

Nanomedicine · Nanotechnology · Targeting · Bioactives · Biodistribution · Barriers

S.D. Mandal (✉)
Department of Pharmacy, Parul University, Vadodara, Gujarat, India

S. Mandal
R&D Head, AGIO Pharmaceuticals Ltd, Bhosari, Maharashtra, India

Y.V. Pathak
College of Pharmacy, University of South Florida Health, Tampa, FL, USA

J.K. Patel
Nootan Pharmacy College, Sankalchand Patel University, Visnagar, Gujarat, India

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