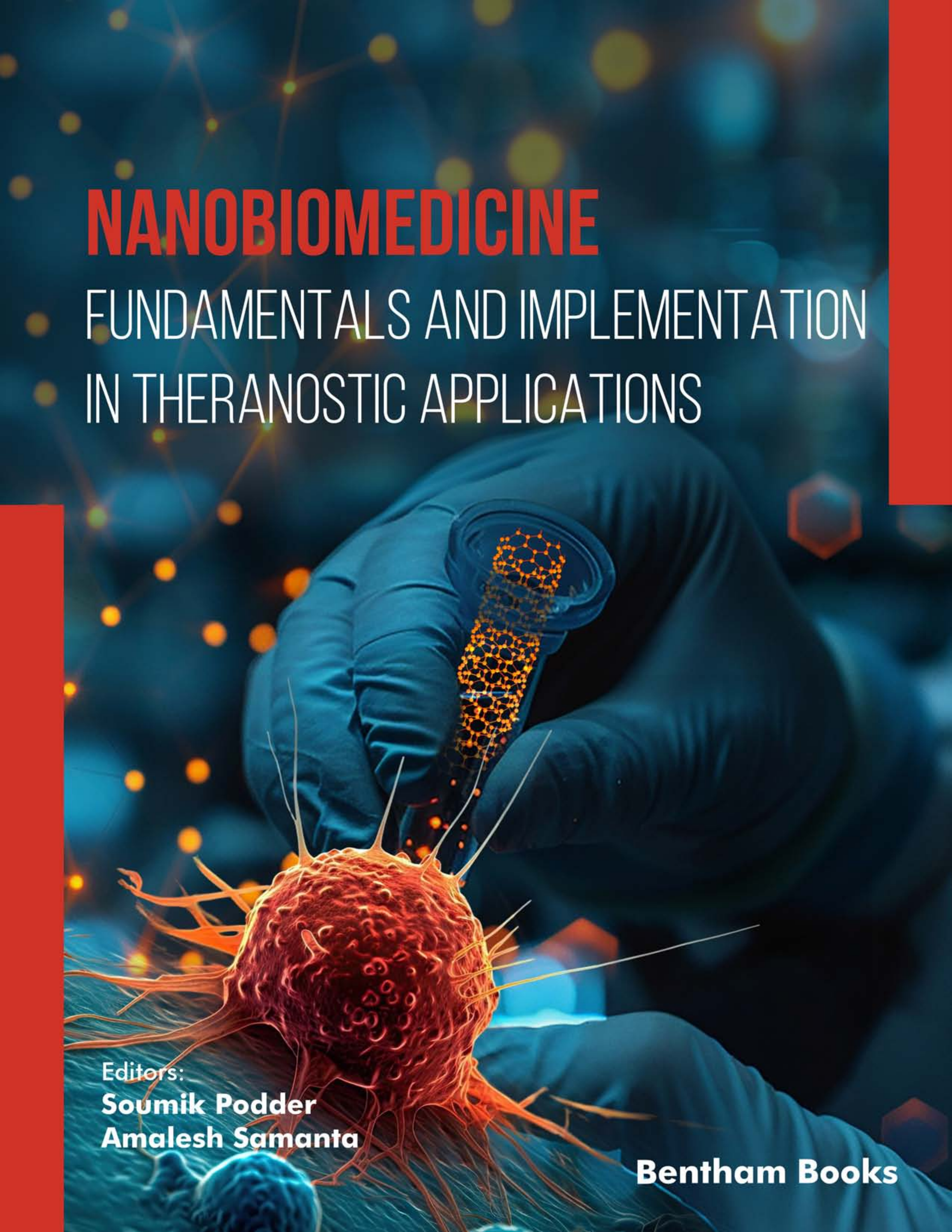

NANOBIOMEDICINE

FUNDAMENTALS AND IMPLEMENTATION IN THERANOSTIC APPLICATIONS

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Bentham Books

Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications

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FOREWORD

The field of nanobiomedicine stands at the precipice of a transformative era in healthcare. The ability to manipulate matter at the nanoscale has opened unprecedented opportunities for diagnosing, treating, and even preventing diseases. This book, Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications, arrives at a crucial juncture, offering a timely and comprehensive exploration of this dynamic field. From its inception, nanobiomedicine has promised targeted therapies, personalized medicine, and earlier disease detection. This promise is now being realized, thanks in part to the synergistic integration of artificial intelligence. Artificial intelligence has the ability to analyze vast datasets, identify patterns, and optimize processes. These key features have accelerated research and development in nanobiomedicine, leading to breakthroughs that were once considered science fiction.

This book expertly navigates the complex landscape of nanobiomedicine, providing readers with a clear understanding of the fundamental principles, diverse applications, and the exciting potential of AI-driven advancements. It meticulously covers key areas, from the basics of nanomaterials and their interactions with biological systems to cutting-edge applications in theranostics, cancer treatment, and neurodegenerative diseases. The book also thoughtfully addresses the challenges and ethical considerations associated with this rapidly evolving field, including risk management and security in AI-based nanomedicinal applications.

What sets this book apart is its holistic approach. It not only delves into the scientific intricacies of nanobiomedicine but also highlights the crucial role of interdisciplinary collaboration. Researchers, clinicians, engineers, and data scientists must work together to unlock the full potential of this field, and this book serves as a valuable platform for fostering such collaboration. I am particularly impressed by the book's focus on the integration of artificial intelligence. The chapters dedicated to AI in nanomedicine formulation, Alzheimer's disease detection, and spinal surgery offer compelling examples of how AI is revolutionizing healthcare. These applications hold immense promise for improving patient outcomes and transforming the way we deliver care.

Nanobiomedicine and AI: Shaping the Future of Healthcare is a must-read for anyone interested in the future of medicine. It is a valuable resource for researchers, clinicians, students, and policymakers alike. I am confident that this book will inspire further exploration, stimulate innovation, and ultimately contribute to the advancement of nanobiomedicine and the betterment of human health.

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PREFACE

The terminology "Biomedicine," also referred to as "Professional Medicine," is predominantly biological medicine. To maintain uniformity in labeling medicine across different cultures, the term Biomedicine was coined by Gaines and Hahn in place of cosmopolitan medicine, western medicine, allopathic medicine, or scientific medicine. This traditional medicine applies physiological and biological principles in clinical practice. This field of medical science is administered by formally trained doctors, nurses, and medical practitioners. The medicinal products are targeted to combat diseases at the macro level and often affect normal cells to a significant extent. Another point of observation in biomedicine is its potential to trigger allergic reactions in patients due to the lack of personalized formulations. There is also no scope for adjusting the shape and size of drugs to achieve highly focused drug delivery.

With the advent of nanotechnology, a branch of physics, a remarkable concept emerged for tuning the shape and size of macro-sized materials in nature. Later, chemical science incorporated synthesis routes to prepare these unique materials. One of the advantages of chemical science is that it offers numerous avenues to control shape and size. These strategies have successfully developed nanomaterials with one-dimensional sizes ranging from 1 to 100 nm. One-dimensional nanotubes, two-dimensional nanosheets, nanoflakes, thin films, three-dimensional hierarchical nanostructures, and zero-dimensional quantum dots have made significant contributions in diverse fields, especially healthcare, due to controlled drug release, targeted drug delivery, and reduced cytotoxicity.

The convergence of nanotechnology and biomedicine, now commonly known as nanobiomedicine, has triggered a revolution in healthcare, offering unprecedented opportunities for diagnostics, therapeutics, and theranostics. For diagnostic purposes, nanomaterials can enter the bloodstream easily due to their extremely small size, enabling effective treatment or faster diagnosis. Various nanomaterials, such as nanoparticles, nanowires, nanoconjugates, and nanorods, have opened new possibilities in medical diagnosis and treatment. These materials not only simplify disease detection by functioning as biomarkers but also highlight medical areas that were previously challenging to diagnose or treat using conventional analytical methods.

Nanomaterials, explicitly referred to as nanomedicine, have transformed therapeutic applications through their remarkable versatility in treating complex diseases. In bacterial inhibition, silver, zinc oxide, and copper nanoparticles demonstrate potent antimicrobial properties by disrupting bacterial cell membranes, generating reactive oxygen species, and interfering with essential cellular processes, offering potential solutions to combat antibiotic resistance. In cancer therapy, engineered nanomaterials, such as liposomes, polymeric nanoparticles, and gold nanostructures, enable targeted drug delivery to tumor sites, minimizing damage to healthy tissues while enhancing therapeutic efficacy. These nanocarriers can be functionalized with targeting ligands that specifically recognize cancer cell receptors, allowing for precise delivery of chemotherapeutic agents, genetic material, or immunomodulatory compounds. Additionally, some nanomaterials exhibit intrinsic therapeutic properties, such as gold nanorods and magnetic nanoparticles, which can convert external energy sources, such as light or magnetic fields, into localized heat for thermal ablation of tumors, creating multifunctional platforms that combine diagnostic and therapeutic capabilities in a single system.

Nanobiomedicine has recently emerged as a revolutionary method for tackling diagnostic and therapeutic challenges. Nanoparticles serve as carriers for drugs and genes in treating various diseases. Their advantageous high surface area-to-volume ratio enables drug- or gene-conjugated nanoparticles to penetrate cell membranes and reach intracellular targets. Through receptor-specific recognition, functionalized nanoparticles can target specific cells, reducing off-target effects. Nanoparticles also protect drugs and genes from the degradation common in conventional delivery methods by encapsulating or shielding these formulations. In addition, nanoparticles offer the benefit of combining therapy and diagnostics into a single theranostic platform, allowing for precise treatment and disease monitoring. These versatile particles can transport both imaging agents and therapeutic molecules (including drugs, DNA, and RNA), enabling simultaneous disease imaging and treatment while eliminating the need for separate procedures. Researchers worldwide are currently investigating nanoparticles' theranostic potential across various applications, from cancer and genetic disorder therapies to vaccine development, demonstrating their remarkable capabilities. This chapter examines various nanoparticles used for drug and gene delivery alongside commonly employed imaging techniques in theranostic approaches.

ABOUT THE BOOK

In the present context, this book, "Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications," focuses on providing an in-depth overview of this rapidly evolving field, exploring its fundamental principles, cutting-edge applications, and the transformative role of artificial intelligence.

Designed with an introductory concept of nanobiomedicine, this book explores its potential applications in healthcare and concludes with AI-assisted patient sentiment analysis. The book deliberately features a diverse examination of nanomedicine's role in healthcare to provide readers with a thorough and progressive understanding of medical advancements.

In this book, an introductory overview of nanobiomedicine with key features, potential applications, future prospects, and challenges such as ethical concerns, toxicity, and regulatory obstacles is presented in a comprehensible manner. Subsequently, implications of nanomaterials in the therapeutic sector, including photodynamic therapy, immunotherapy, and gene therapy, are discussed in detail. Simultaneous performance in diagnosis and therapy is also highlighted, where nanomaterials can act as vectors for drugs and genes in the treatment of various disease conditions. Their high surface area-to-volume ratio is a positive factor, as it allows drug- or gene-conjugated nanoparticles to traverse cell membranes and access intracellular targets. Both imaging agents and therapeutic molecules [drugs, DNA, and RNA] can be carried by nanoparticles, whose multifunctionality enables simultaneous disease imaging and treatment, reducing the need for separate interventions. This book also highlights the diagnostic portfolio of nanomaterials in a profound way so that interested researchers can gain ample guidance from the chapter. In this particular chapter, 2-dimensional nanomaterials, quantum dots, nanocomposites, etc., are explored as disease biomarkers, and nanodispersions are discussed. A special literary discussion focuses on cancer treatment and diagnosis by nanomaterials, where nanomedicine has revolutionized cancer therapy by enabling targeted drug delivery to tumor sites through functionalized nanocarriers, minimizing damage to healthy tissues while maximizing therapeutic efficacy. In cancer diagnosis, nanoparticles serve as contrast agents for enhanced imaging techniques, allowing earlier detection of malignancies at the molecular level before morphological changes become apparent. These nanoscale platforms can also be engineered as theranostic agents that combine both diagnostic and therapeutic functions, permitting real-time monitoring of treatment response while simultaneously delivering anticancer drugs or mediating thermal ablation therapies. Interestingly, the theme of the book has slightly shifted to Artificial Intelligence-based disease detection due to the fact that in the modern healthcare industry 5.0 and 6.0 under smart society 5.0 and 6.0, artificial intelligence is an extensively dominant tool to clinically diagnose, analyze diseases, and assist patients. In this regard, the book includes one chapter on Machine Learning-assisted Alzheimer's disease detection that diligently helps patients achieve better treatment and guides doctors to use suitable artificial intelligence models for improved accuracy in prediction. A spontaneous question arises whether there is any scope for artificial intelligence-mediated nanomedicine formulation to design drugs that are more personalized and effective in combating disease. Of course, the book incorporates one chapter on artificial intelligence-based drug discovery, especially for allergic diseases. A comprehensive and more profound generalized conceptualization of artificial intelligence-based nanomedicine formulation is presented in the succeeding chapter. To account for the challenges of artificial intelligence-based nanomedicine formulation and disease treatment, a risk management and regulatory measurement framework is needed for AI-driven nanomedicine, including preventive security measures and real-time monitoring with a stringent algorithm validation process. Finally, the book encompasses sentiment analysis of patients when they are suffering from neurodiseases or cancer. One chapter is dedicated to these patients, where natural language processing techniques (NLP) are used to analyze their emotions and sentiments for more effective treatment. The selection of this chapter is motivated by the aim of enabling healthcare systems to extract emotional insights from patient feedback, social media posts, and clinical notes. By analyzing patient sentiments, healthcare providers can identify areas of dissatisfaction, monitor mental health trends, and personalize treatment approaches based on emotional responses to care. This technology facilitates a more empathetic healthcare ecosystem by quantifying subjective experiences that traditionally went unmeasured, allowing for continuous improvement of patient experiences while providing early warning signals of potential issues in care delivery. NLP-based sentiment analysis bridges the communication gap between patients and healthcare systems, transforming qualitative expressions into actionable intelligence that drives more responsive and emotionally intelligent healthcare services. This book is truly interdisciplinary in its disposition and emerges as an efficient reference for materials scientists, biotechnologists, AI researchers, and medical practitioners.

ORGANIZATION OF THE BOOK

The journey through this book begins with an introduction to the core concepts of nanobiomedicine, laying the groundwork for understanding the intricate interactions between nanomaterials and biological systems, and the reasoning behind the implications of nanomedicines in the evaluation and diagnostics of cancer and other infectious diseases (Chapter 1). In this chapter, the methodologies of nanomedicine injection for tissue engineering and regenerative medicine are depicted with intense focus. Some recent advancements, including nanorobots for customized medications, are highlighted for readers' interest. Finally, some constraints such as ethical concerns, toxicity, and regulatory obstacles are addressed in this chapter, providing a realistic view of nanomedicines.

The diagnostic prowess of nanomaterials is further explored in Chapter 2, showcasing their utility in early disease detection and personalized medicine. This chapter provides a detailed overview of different nanomedicine structures, including nanoparticles, 2D materials, quantum dots, nanofibers, nanowires, nanorods, nanodispersions, carbon nanotubes, and nanocomposites, and their uses in imaging, biosensing, and diagnostics, aiming to give readers a clear understanding of nanomedicine's applications.

Chapter 3 expands on this, focusing specifically on the exciting realm of theranostics, where diagnosis and therapy are seamlessly integrated at the nanoscale. In this chapter, the implications of different types of nanomaterials, such as micelles, organic nanoparticles, and gold nanoparticles, in drug delivery, imaging, Point of Care (POC) therapy, and gene therapy are explained in a comprehensible fashion with concomitant analysis of strategies for sustained drug release.

The fundamental ideas and key points of nanomedicine-induced theranostic systems are then matured in Chapter 4, where we delve into the diverse applications of nanomaterials in therapeutic interventions, highlighting their potential for targeted drug delivery and enhanced treatment efficacy. The chapter comprehensively discusses major progress in nanomaterials-mediated healthcare, including immunotherapy, gene therapy, tumor treatment, and vaccine development. Additionally, this chapter recommends different clinical translations of nanomedicines and examines associated challenges currently faced by the field.

Chapter 5 examines the use of nanomedicine for combined therapy and diagnosis in cancer treatment. This chapter illustrates how nanomedicine has developed to address limitations in traditional cancer therapies. It pays particular attention to recent progress in using various nanomedicine types, such as upconversion, plasmonic, magnetic, quantum dot, carbon, Prussian blue, mesoporous silica, lipid-based, and polymeric nanoparticles, in clinical cancer treatment. The chapter concludes by discussing the future potential and obstacles of implementing nanomedicine in clinical practice.

Chapter 6 presents a fascinating exploration of machine learning (ML)-based approaches for early detection of Alzheimer's disease, demonstrating the power of AI in neurodegenerative disorders for accurate and early detection of intermediate stages. While the promise of nanobiomedicine is immense, challenges remain.

Chapter 7 delves into AI-mediated drug delivery, including oral, intravenous, intramuscular, subcutaneous, and transdermal routes, especially for allergic patients, by addressing challenges in traditional nanomedicine formulation. This chapter addresses inherent challenges in nanomedicine-mediated traditional theranostic applications, such as pharmacokinetics, bioavailability, and targeted action, acknowledging the complexities and potential limitations. However, these challenges are being actively addressed, particularly with the integration of AI methodologies—including machine learning, deep learning, and natural language processing—into the development of next-generation drug delivery platforms.

Besides experimental synthesis of nanomaterials and their implications in theranostic applications, modern technologies such as Artificial Intelligence (AI) and its associated sister concerns pervade theranostic systems to reduce tedious human efforts and provide a smart, decisive, and justifiable healthcare system. In today's hectic life, hypertension and oxidative stress are natural phenomena for every individual and, in most cases, they are untreated or casually treated, resulting in neurodegeneration in individuals over the age of 65. Alzheimer's and Parkinson's are the two most prevalent diseases frequently developed in adults, especially senior citizens, making early identification and medication of utmost priority.

Keeping this in view, Chapter 8 highlights the crucial role of AI in nanomedicine formulation and applications, showcasing its ability to accelerate research and development. This chapter illustrates revolutionary breakthroughs due to AI regarding existing limitations of nanomedicine, specifically in production scales, regulatory burdens, and nanomaterial toxicity. At the outset, the chapter highlights ethical, regulatory, and data-related issues that arise from the integration of AI with nanomedicine.

This book is intended for a broad audience, including researchers, clinicians, engineers, and students interested in the intersection of nanotechnology, biomedicine, and artificial intelligence. We hope that it serves as a valuable resource, inspiring further exploration and contributing to the advancement of this dynamic field. A tapestry of knowledge, woven with threads of expertise and spun with the dedication of insightful minds, has been presented to us. We stand in gratitude, bathed in the luminescence of our contributory authors' intellectual contributions. These are not merely words on a page, but seeds of wisdom, planted with the intention of nurturing a future harvest. We envision these ideas blossoming, becoming guiding stars for burgeoning researchers and clinicians, illuminating their paths toward a sustainable, intelligent healthcare society. Their work, a beacon in the vast expanse of medical innovation, promises to ignite a chain reaction of discovery, fostering a legacy of healing and progress.

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ABOUT THE BOOK

In the present context, this book, " Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications," focuses to provide an in-depth overview of this rapidly evolving field, exploring its fundamental principles, cutting-edge applications, and the transformative role of artificial intelligence.

Designed with an introductory concept of nanobiomedicine, this book explores its potential applications in healthcare while concluding with AI-assisted nanomedicine formulation. The book deliberately features a diverse examination of nanomedicine's role in healthcare to provide readers with a thorough and progressive understanding of medical advancements.

In this book, at first an introductory idea of nanobiomedicine with key features, potential possible applications, future prospects, challenges like ethical concerns, toxicity and regulatory obstacles are presented in a comprehensible manner. Simultaneous performance in diagnosis and therapy is also illuminated in this book where the nanomaterials can act as a vector for drugs and genes in the treatment of various disease conditions. Their high surface area-to-volume ratio is a positive factor as it allows the drug or gene conjugated nanoparticles to traverse cell membranes and access intracellular targets. Both imaging agents and therapeutic molecules [drugs, DNA and RNA] can be made to be carried by nanoparticles, the multi-functionality of which enables simultaneous disease imaging and treatment, reducing the need for separate interventions. Afterwards, implications of nanomaterials in therapeutic sector including photodynamic therapy, immunotherapy, gene therapy is discussed in a detailed fashion. This book also highlights separately diagnostic portfolio of nanomaterials in a profound way so that interested researcher can get ample guidance from the chapter. In this particular chapter, 2-dimensional nanomaterials, quantum dots, nanocomposites etc. are used as disease biomarkers, nanodispersion etc. A special literary discussion was made on cancer treatment and diagnosis by nanomaterials where nanomedicine has revolutionized cancer therapy by enabling targeted drug delivery to tumor sites through functionalized nanocarriers, minimizing damage to healthy tissues while maximizing therapeutic efficacy. In cancer diagnosis, nanoparticles serve as contrast agents for enhanced imaging techniques, allowing earlier detection of malignancies at the molecular level before morphological changes become apparent. These nanoscale platforms can also be engineered as theranostic agents that combine both diagnostic and therapeutic functions, permitting real-time monitoring of treatment response while simultaneously delivering anticancer drugs or mediating thermal ablation therapies. Interestingly the theme of the book has slightly transited to Artificial Intelligence based disease detection because of the fact that, in modern healthcare industry 5.0 and 6.0 under smart society 5.0 and 6.0, artificial intelligence is extensively ruling agent to clinically diagnose, analyze diseases and give assistance to patients. In this regard, the book includes one chapter on Machine learning assisted Alzheimer disease detection that diligently help patients for better treatment and mentoring doctors to use suitable artificial intelligence models for better accuracy in prediction. A spontaneous inquisition arises whether there is any scope of artificial intelligence mediated nanomedicine formulation so as to design the drug more personalized and effective in disease combating. Of course, the book incorporates one chapter on artificial intelligence-based drug discovery specially for allergic diseases. A comprehensive and more profound generalized conceptualization on artificial intelligence-based nanomedicine formulation, has been realized in the succeeding chapter. This book is a truly interdisciplinary in its disposition and startlingly turns out as efficient reference for materials scientist, biotechnologist, AI researchers and medical practitioners.

ORGANIZATION OF THE BOOK

The journey through this book begins with an introduction to the core concepts of nanobiomedicine, laying the groundwork for understanding the intricate interactions between nanomaterials and biological systems (Chapter 1). We then delve into the exciting realm of theranostics, where diagnosis and therapy are seamlessly integrated at the nanoscale. (Chapter 2) Chapter 3 focuses on diverse applications of nanomaterials in therapeutic interventions, highlighting their potential for targeted drug delivery and enhanced treatment efficacy. The diagnostic prowess of nanomaterials is further explored in Chapter 4, showcasing their utility in early disease detection and personalized medicine. A significant portion of the book is dedicated to the application of nanomedicine in combating cancer, a disease that continues to challenge modern medicine. Chapter 5 examines the use of nanomedicine for conjugated therapy and diagnosis in cancer treatment, while Chapter 6 presents a fascinating exploration of machine learning-based approaches for early detection of Alzheimer's disease, demonstrating the power of AI in neurodegenerative disorders. While the promise of nanobiomedicine is immense, challenges remain. Chapter 7 delves into AI-mediated drug delivery, especially for allergic patients, by addressing challenges in traditional nanomedicine formulation. This chapter addresses the inherent challenges in nanomedicine-mediated traditional theranostic applications, acknowledging the complexities and potential limitations. However, these challenges are being actively addressed, particularly with the integration of artificial intelligence. Chapter 8 highlights the crucial role of AI in nanomedicine formulation and applications, showcasing its ability to accelerate research and development.

This book is intended for a broad audience, including researchers, clinicians, engineers, and students interested in the intersection of nanotechnology, biomedicine, and artificial intelligence. We hope that it serves as a valuable resource, inspiring further exploration and contributing to the advancement of this dynamic field. We are indebted to the contributing authors for their expertise and dedication, and we hope that it serves as a valuable resource, inspiring further exploration and contributing to the advancement of this dynamic field. A tapestry of knowledge, woven with threads of expertise and spun with the dedication of insightful minds, has been gifted to us. We stand in gratitude, bathed in the luminescence of our contributory authors' intellectual contributions. These are not merely words on a page, but seeds of wisdom, planted with the intention of nurturing a future harvest. We envision these ideas blossoming, becoming guiding stars for burgeoning researchers and clinicians, illuminating their paths towards a sustainable, intelligent healthcare society. Their work, a beacon in the vast expanse of medical innovation, promises to ignite a chain reaction of discovery, fostering a legacy of healing and progress.

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CHAPTER 1

Fundamentals of Nanomedicine

Amalesh Samanta[1,*], Suparna Garai[1], Pranab Naskar[1], Sohini Chatterjee[1], Mousumi Das[1], Abhishek Mohanta[1] and **Mousumi Tudu[1]**

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Abstract: Nanomedicine is a multidisciplinary field merging nanotechnology with medicine to address complicated health challenges at the cellular and molecular levels. The fundamental theory involves operating with materials at the nanoscale (1-100 nanometers), where distinctive physical, chemical, and biological characteristics become apparent. These nanoscale substances can interact with cellular systems in novel ways, allowing precise diagnostics, selective drug delivery, and novel therapeutic methods. Key developments include the progress of nanoparticle-derived delivery systems that enhance the bioavailability and singularity of treatments, decreasing side effects. Nanobiomedicine also plays a crucial role in evaluation and diagnostics, where nanosensors and imaging agents enable the early detection of diseases, including cancer and other infectious diseases. Additionally, nanotechnology has potential in regenerative medicine and tissue engineering, where nanomaterials help in tissue repair and cell growth. Recent advancements, for instance, the incorporation of nanorobots for minimum invasive processes and the utilization of biocompatible nanostructures for customized medications, highlight the revolutionary potential of nanobiomedicine. Although challenges like ethical concerns, toxicity, and regulatory obstacles must be recognised for widespread clinical application, with continuous research, nanobiomedicine promises to transform healthcare, providing more potent, personalized, and reduced invasive medical solutions.

Keywords: Cancer therapy, Diagnostic imaging , Nanomedicine , Nanoparticles, Regenerative medicines, Targeted drug delivery.

INTRODUCTION

Definition and Scope: Nanomedicine is a multidisciplinary field of science that includes physics, chemistry, engineering, biology, medicine, and allied sciences for the detection and treatment of diseases with the help of nanotechnology. The

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ultimate goal of nanomedicine is to target the human body at the atomic and molecular levels, repairing it in a manner similar to how we maintain conventional machines today [1]. The spectrum of nanobiomedicine is vast, encompassing areas such as advanced diagnostic imaging methods, targeted drug delivery, tissue engineering, and regenerative medicines. By utilizing the noble and unique aspects of nanomaterials such as high surface-area volume ratio, quantum effects, nanobiomedicine can achieve much higher accuracy in targeting tissues (more specific), thereby increasing the therapeutic efficacy and decreasing the adverse effects.

Historical Background: It is recognized that the original foundation of nanotechnology dates back to Richard Feynman's 1959 lecture, "There's Plenty of Room at the Bottom," in which he proposed the concept of nanotechnology. Feynman is known for his work in the theory of quantum electrodynamics. In that seminar, he proposed the idea of directly manipulating atoms and molecules [2]. Although the term "nanotechnology" was introduced by Norio Taniguchi, a professor at the Tokyo University of Science, to describe processes such as semiconductor-like thin film deposition and ion beam machining that demonstrate precise control at the nanometer scale, in 1974 [3]. A significant milestone was marked with the introduction of Scanning Tunneling Microscopy (STM) by Gerd Binning and Heinrich Rohrer in the 1980s [4]. The unification of nanotechnology and biomedical sciences, which began in the late 1990s and 2000s, is driven by the advancements in nanofabrication techniques and nanomaterials. Developments in nano-materials-based delivery of drugs and nanoscale imaging methods highlight the prospect of this multidisciplinary field in revolutionizing the healthcare system [5, 6].

Interdisciplinary Nature: The fundamentals of nanomedicine are inherently interdepartmental, leveraging wisdom and methodologies from several fields, which include physics, chemistry, biology, engineering, and medicine. This intersection is crucial for addressing the complex design and implementation of nanoscale tools and materials for biomedical applications. For example, the formation of nanoparticles for drug delivery requires expertise in chemistry and material science to ensure functionality and biocompatibility [7].

Medicine and cell biology also play an important role in understanding the relationship and interaction between nanoparticles and biological systems. It is crucial to focus on collaborative efforts from diverse disciplines in order to translate the findings in the laboratory into clinical applications, thereby nurturing innovation and accelerating the evolution of novel nanobiomedical technologies (Fig. **1**).

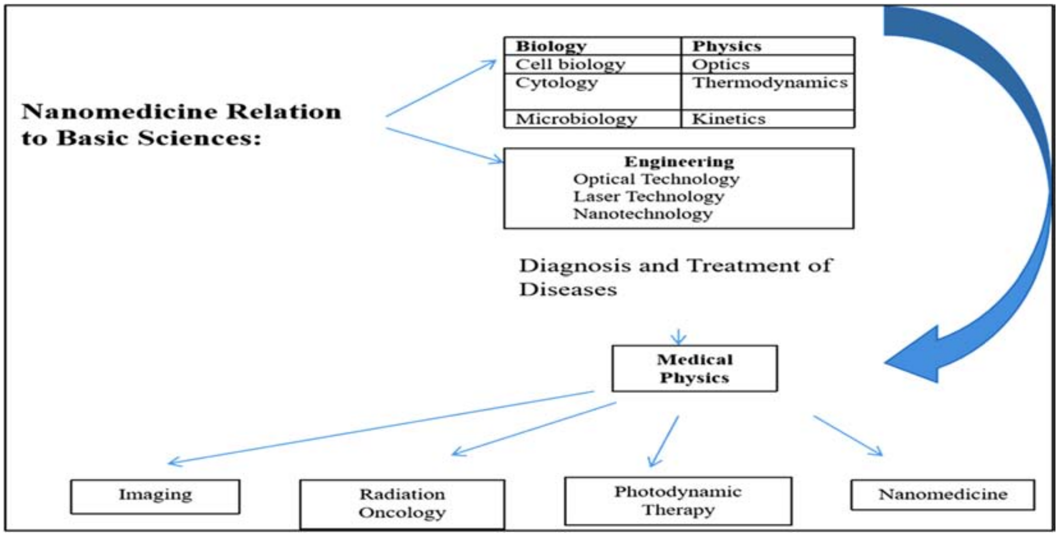

Fig. (1). Relation between nanomedicine and basic sciences.

Basic Concepts of Nanotechnology

Nanomaterials and Nanostructures

Materials with structural characteristics smaller than 100 nanometers in one or more dimensions are known as nanomaterials. They can be zero-dimensional, known as nano-particles, one-dimensional, called nanotubes and nano-wires, two-dimensional, known as nanofilms and nanosheets, or can be three-dimensional, which are called nanocomposites. Nanostructures are attributed to the specific configuration of atoms or molecules at the nanoscale, which often provide materials with unique physical and chemical properties compared to their bulk counterparts [8].

Properties: Due to increased surface area and quantum effects, materials at the nanoscale exhibit distinct properties. These characteristics include electrical conductivity, enhanced mechanical strength, chemical reactivity, and optical behaviour. For example, gold particles in their nano form can be used in imaging and therapeutic applications, as they exhibit optical properties that are size-dependent [9]. Carbon Nanotubes are used in biosensor applications and tissue engineering because of their exceptional mechanical strength [10].

Fabrication and Characterization Techniques

Nanobiomedicine uses nanotechnology to address challenges in healthcare, such as targeted drug delivery, diagnostics, and imaging. This field relies on robust

CHAPTER 2

Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications

Pratik Talukder[1,*], **Sreejita Das**[2], **Mrinmoy Dasgupta**[1], **Aniket Hazra**[1], **Sayantan Biawas**[1], **Swastika Mohanta**[1], **Sayantika Hore**[1] and **Milan Karmakar**[1]

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Abstract: In recent years, nanobiomedicine has emerged as a transformative approach to addressing challenges in diagnosis and therapy. Nanoparticles can act as a vector for drugs and genes in the treatment of various diseases. Their high surface area-to-volume ratio is a positive factor, as it allows the drug- or gene-conjugated nanoparticles to traverse cell membranes and access intracellular targets. Functionalized nanoparticles can target specific cells using receptor-specific recognition, thereby minimizing off-target effects. Degradation of drugs is common in conventional delivery methods, but nanoparticles help prevent this by encapsulating or shielding the drug formulations. In addition to the aforementioned benefits, nanoparticles can be used to integrate therapy and diagnostics into a single platform, known as theranostics, enabling precise treatment and monitoring of diseases. Both imaging agents and therapeutic molecules (drugs, DNA, and RNA) can be carried by nanoparticles, whose multifunctionality enables simultaneous disease imaging and treatment, reducing the need for separate interventions. Currently, studies are being conducted worldwide on the theranostic potential of nanoparticles under various conditions, ranging from cancer therapy and treatment of genetic disorders to vaccine development, which speaks volumes about their capabilities. In this chapter, we review various nanoparticles used for drug and gene delivery alongside commonly utilized imaging techniques for theranostic applications.

Keywords: Biosensors, DNA, Gene therapy, Nanobiomedicine, Nanomaterials, Point-of-care devices, RNA detection, Targeted drug delivery.

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INTRODUCTION

A fundamental benefit of nanotechnology in medicine is the nanoscale size of the particles, which generally range from 1 to 100 nm. This small size allows nanoparticles to easily penetrate human cells, making them especially efficient in targeted drug delivery as well as disease detection. Moreover, nanoparticles function as a protective armor around therapeutic agents, preventing their degradation in the blood by the time they reach the target site. Nanoparticles, designed with antibodies or other biomolecules, help in the precise targeting of diseased cells while sparing healthy tissues, thereby reducing systemic side effects [1]. There are many types of nanoparticles, like liposomes, polymeric nanoparticles, dendrimers, gold nanoparticles, and quantum dots, which are now widely used for diagnostic purposes [2].

Modern drug delivery systems based on nanotechnology address many limitations of traditional therapies by enhancing efficacy and reducing side effects. For example, ions have great potential in targeted drug delivery with applications in cancer treatment. Such nanoparticles can exhibit high binding efficiency and be magnetically guided to specific locations in the body. Functionalization of ions with antimicrobial peptides, such as lasioglossin III from bee venom, exhibits enhanced antimicrobial activity, and the cationic nature of these peptides improves the potential for binding. Studies have shown that drug-loaded nanoparticles exhibit enhanced antimicrobial activity and reduced cytotoxicity compared to free drugs, making them promising candidates for controlled and precise drug delivery [3]. The nano-bio interface has also transformed personalized medicine, enabling highly precise therapeutic interventions. The leading players in this transformation are multifunctional nanoparticles, capable of simultaneously delivering and imaging drugs. These so-called “theranostic” nanoparticles enable real-time monitoring of treatment responses, thereby enhancing the efficacy of therapies while simultaneously reducing systemic toxicity. The same principles that underlie the development of nanoparticle-based platforms for vaccines emphasize the enhancement of antigen delivery and immune stimulation. Such approaches have proven to be particularly effective in generating robust and durable immune responses against infectious diseases and cancers. Additionally, antimicrobial nanomaterials primarily aid in infection control, while nanovaccines and prophylactic drug delivery systems help mitigate the spread of infectious agents, underscoring the versatility of nanotechnology in addressing global health challenges [4].

Although the toxicity of nanomaterials remains a significant consideration in their biomedical applications, the cytotoxicity of nanoparticles proves invaluable for targeting cancer cells, whereas uncontrolled exposure can affect healthy tissues.

Thus, it has become very important to understand nanotoxicity in designing safer nanomaterials. Recent advances in nanotoxicity research have led to the development of this aspect of nanomaterials, where surface modifications, biodegradable materials, and functional coatings are being used to minimize adverse effects. These strategies ensure selective toxicity to diseased cells while maintaining biocompatibility. Such advances are pivotal in developing safe and effective nanobiomedicine solutions for treating complex diseases, such as cancer [5]. Nanocarrier technologies have proven vital in overcoming many limitations associated with conventional drug delivery. Among these nanocarriers, those with unique physicochemical properties are used to treat a wide range of conditions, from microbial infections to genetic disorders and cancers. Despite this tremendous potential, challenges are still related to the limited drug capacity of these nanocarriers, poor solubility, and suboptimal targeting. Innovations in nanocarrier systems, such as micelles, hydrogels, nanocomposites, and microneedles, could address such issues. Advanced features that allow sustained drug release, increased solubility, and responsive releasing mechanisms have made these systems indispensable in modern medicine. An example is the combination of multiple material properties that gives nanocomposites superior functionality, while hydrogels represent a versatile platform for encapsulating and releasing drugs. Microneedles are an innovative method for delivering drugs and vaccines in a minimally invasive way while maintaining efficacy and patient compliance [6].

Another very intriguing innovation in this field of nanotechnology and biomedical science is autonomous nanobiomedicine. Currently, it is becoming possible to eliminate external intervention by launching nanoparticles that can autonomously navigate the body and release therapeutic agents with precision and control. Such interfacial engineering between nanoscale tools and disease detection and treatment processes of autonomous nanobiomedicine promotes the possibility of rapid, personalized assessment and intervention. However, before successful translation to the clinic, there are concerns regarding reproducibility and safety, as well as regulatory hurdles. Prerequisites for understanding the behaviour of autonomous systems include appropriate preclinical studies for the safe application of them in patients. One factor that would determine the success of such a promising field is finding the right balance between innovation and patient safety [7]. The advanced properties, such as high surface-to-volume ratios and a balance of strength and flexibility, of nanomaterials have been exceedingly useful in medicine. These nanomaterials are utilized in disease diagnosis kits in an easy and non-invasive manner, serve as bioimaging agents in biological imaging, and are incorporated into formulations for therapeutic purposes. Liposomal nanocarriers, for example, encapsulate drugs for targeted delivery, while nano-based scaffolds are engineered to enhance bone tissue regeneration. Improvements

CHAPTER 3

Nanomaterials in Therapeutic Application

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Abstract: Using the special phenomenon known as the increased permeability and retention (EPR) effect, the idea of nanomedicine has seen tremendous development in recent decades. Integration of principles based on nanotechnology into diagnostics and medicines has led to major progress in imagining, precision medicine, and targeted delivery of drugs. With a special focus on cancer therapy, countless nanomedicines have been invented and used for the treatment of a variety of diseases. Nanomedicine has recently been applied in a number of cutting-edge sectors, such as tissue engineering, immunotherapy, vaccines, gene transfer, and diagnostics. Concurrent drug administration, therapeutic monitoring, and imaging are made possible by multifunctional nanomedicines, enabling prompt reactions and individualized treatment regimens. This chapter mainly highlights the major progress made in nanomaterials and their probable beneficial uses in the fields of biology and medicine. In addition to this, this chapter also refers to the different clinical translations of nanomedicines and the significant problems that are currently being faced by nanomedicine to overcome the clinical translation barrier.

Keywords: Nanomedicine, Photodynamic Therapy, Tissue Engineering , Targeted drug delivery.

INTRODUCTION

The knowledge of nanotechnology was primarily introduced by Richard Feynman, a Physicist, in the year 1959 during a conversation on developing objects at the molecular and atomic levels. These days, most scientists have faith that nanotechnology is the most capable technology development in the 21st century. They have premeditated that nanotechnology was the new method that has the capability for studying medical conditions. In the last 10 years, the funding for the development and research of nanotechnology has increased, which signifies that nanotechnology will lead the new generation towards productivity

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and success [1]. Additionally, the usage of nanomedicine has widened new possibilities, predominantly in the treatment of cancer because it has accuracy, pointing, high effectiveness, and lower antagonistic effects [2]

Abundant NPs, such as inorganic NPs, polymeric NPs, are providing advantages in the therapy field, which include both *in vivo* and *in vitro* drug stability, smooth surface modification, and easy therapeutic efficacy [3]. It has been recently discovered that NPs can now couple with bispecific molecules by the action of physical or chemical techniques, and NPs can also attach to certain biological events like interaction between receptor-ligand, antigen-antibody collaboration, and DNA-DNA hybridization [4]. The engineered NPs are planned to regulate the release of drugs and partially interact with specific cells that safeguard the targeted medication transfer while preventing enzymatic degradation [3]. During the nanoparticles design, there are a few things that are kept in mind while using them, such as particle shape, surface charge, size, and hydrophobicity. All of these factors are sensitive reasons for the nanoparticles to reach the targets. The nanoparticles that are smaller than <5 nm may be washed out from the blood vessels during movement, whereas the larger nanoparticles that are larger than >100 nm are retained in the ECM, and the medium-sized nanoparticles of size between 5 nm to 100 nm stay inside the bloodstream and are smoothly conveyance to the targeted sites. The size as well as the shape are the substantial important factor that impacts the clearance of nanoparticles from the lymph nodes. Most of the nanoparticles are spherical, but due to the advancement of nanoparticle engineering, different diversity forms have been developed, such as prisms, stars, rods, and discs. In addition to shape and size, the surface charge carrier plays a significant function in immune response activation and cellular internalization, also it influences how cells efficiently engulf the nanoparticles. Comparing the positively and negatively charged, it shows that positively charged nanoparticles have a sturdier immunological response, but they show decreases in the tissue permeability because they often get trapped in the ECM of negatively charged [5]. That's why engineered nanoparticles are more beneficial than conventional therapeutics, which include preventing biological depletion, and targeting tumor cells *via* active targeting while reducing the toxicity of cells and enhancing bioavailability and *in vivo* stability. Nanoparticles are designed in such a manner that they release the payload at a particular targeted site [6]. However, the precise application is identified by the surface of physics, chemistry, thermodynamics, and toxicological impacts [4].

The application of nanomedicine serves as a key approach in cancer treatment, leveraging the enhanced permeability and retention effect [7]. In different book chapters and articles, the mechanism, history, and future perspective of EPR have been well documented [2]. Therefore, it acts as a dynamic role in the accumulation of nanomedicine for the tumor tissue, as it boosts the effectiveness, along with decreasing side effects and systemic exposure. The impact of EPR signifies the process of accumulation of selective macromolecule particles in the tumor tissue, and is eased by the exceptional pathophysiological and anatomical features of tumor blood vessels. The legitimacy of EPR effects has been recognized not only in animal models, but also in humans, which include situations like renal, metastatic, and liver breast cancer [8 - 10]. In a study, it has been discovered that human metastatic breast cancer and renal tumors have shown a substantial impact on the development of the anti-cancer nanomedicines [8, 9]. According to the effects of EPR, it has been demonstrated that nanomedicine is beneficial for the treatment of cancer, in contrast to earlier traditional smaller molecular anti-cancer drugs that have a tendency to accumulate extensively in ordinary organs, tissues, which leads to adverse systemic impacts [11 - 13]. Hence, nanomedicine offers an improved and promising treatment option. In the last two decades, there has been significant advancement and growth in the arena of anti-cancer nanomedicine.

In recent years, various nanomedicines have been developed and designed for cancer therapy, which are less invasive, such as photodynamic therapy, which is a nanoprobe-based approach, and magnetic hyperthermia therapy using magnetite, as well as BNCT; all of these have therapeutic potential [2]. Moreover, the use of nanomedicine in advanced biomedical fields like gene therapy, immunotherapy, and deterrent medicine has gained substantial consideration. A prominent illustration is the accomplishment of the COVID-19 mRNA vaccine that uses nanoparticles composed of lipids for the drug delivery process [14]. In this framework, this article examines the potential uses of nanomedicines in the development of cancer therapy and various biological fields.

The Applications of Nanomedicine in Photodynamic Therapy

Nano-Engineered Photosensitizers Propose a Promising Strategy for Cancer Treatment

In spite of the constant development of various methods of tumor treatment, substantial challenges continue, which include resistance to drugs, non-specificity, lower response rates, and various side effects related to toxicity [15]. PDT is a targeted alternate and is non-intrusive, whereas activated-light PS produces ROS, which acts as a cell death of tumor cells. Therefore, PDT provides an effective and prominent approach for addressing the upcoming strategies for the treatment of tumor cells [16]. Though the process of PDT clinical trial is resisted by the restrictions of old-style photosensitizers, mainly for the absence of tumor selectivity, consequential in its relatively lesser number of applications in recent

CHAPTER 4

Nanomaterials in Diagnostic Applications

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Abstract: In the past few years, nanomaterials have emerged tremendously for applications in the field of diagnosis and medicine. They have gained attention due to their extremely small size and mouldable characteristics. This chapter focuses on the different nanomaterials developed for use in diagnostics, treatment, and also as potent drug carriers. These nanomaterials, being very small in size, easily enter circulation to provide the desired therapeutic efficacy or facilitate faster diagnosis. Different nanomaterials, including nanoparticles, nanowires, nanoconjugates, and nanorods, have paved new dimensions in diagnosis and treatment. Not only do they facilitate the detection of diseases by serving as biomarkers, but they also bring to the forefront areas of medicine that were previously difficult to treat or detect using primitive and traditional analytical techniques.

Keywords: Nanomedicine, Nanotubes, Nanofilms, Nanofibers, Nanomembranes, Targeted Drug Delivery.

INTRODUCTION

The presence of several pathogenic viruses, along with microbes and their mutations, and the bacterial resistance towards antibiotics, diseases like cancer, diabetes, and other genetic disorders, poses a severe challenge to the medical system and also humanity. In order to treat such cases, it is very important to make an initial diagnosis and arrest the infection. In this regard, the recent development in the field of nanotechnology has paved the way to solve such crises in medicine and healthcare [1, 2].

Nanotechnology involves the use of nanomaterials, which are very tiny in size, ranging from 1-100 nm, but possess a bigger surface area. Nanomaterials are tested to have outstanding thermal, chemical, and optical properties, making

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them a potential candidate in the biomedical field of research and development. Based on dimensions, nanomaterials can be zero-dimensional [nanoparticles; NPs], one-dimensional [nanorods, nanotubes], and two-dimensional [nanofilms, nanolayers] [3].

The ultra-small size and good surface area, prominent mechanical properties, and optical and magnetic behaviour have made nanoparticles a widely accepted nanomaterial for biomedical applications. The nanodevice should be easily synthesized and biocompatible with the human body. Nanodevices smaller than 500 Angstroms easily penetrate cell barriers, whereas thr ones that are nearly 200 Angstroms can circulate throughout the body, escaping blood vessels. Hence, they can interact with the body both extracellularly and intracellularly. Nanodevices can be used to detect and monitor cell abnormalities in regions that were previously not reachable, since they can reach all parts of the body [4].

The small size of these materials causes atoms and molecules to be mostly located at their surface, providing them with distinct physicochemical properties from those of bulk. Due to this arrangement of surface atoms, they tend to possess low binding energy and low melting point. The smaller size of nanomaterials leads to increased surface area per unit mass, thereby enhancing their chemical properties [5].

The process of nanomaterial engineering involves two different approaches, namely, top-down and bottom-up. In the case of the top-down method, larger pieces of material are broken down to the required size of the nanostructure. In the bottom-up procedure, single atoms and molecules are clustered to form a nanostructure. This is done with the help of supramolecular chemistry, biotechnology, and scanning probes. Both approaches are important in their own ways of nanomaterial synthesis, of which the bottom-up approach finds greater application [6].

Nanomaterials have combined several disciplines, including biotechnology, chemistry, molecular biology, and medicine, to develop newer approaches for medical diagnosis. They also offer high sensitivity toward detecting even very low concentrations of parasites, antibodies, or any other microbes in blood samples. This, in turn, helps to detect a disease at a very early stage, helping in providing better treatment facilities by healthcare professionals [7].

Nanotechnology also plays a crucial role in detecting cancer and its treatment, along with other diseases like gastrointestinal, antibacterial, antifungal, cardiovascular, neural, inflammatory, infectious, and autoimmune disorders, *etc* [8].

This book chapter focuses on the benefits of nanomaterials in biological sciences and their future in the medical field, particularly in diagnosis and treatment. We have elaborated the role of nanoparticles, quantum dots, one and two-dimensional nanomaterials, composites, carbon nanotubes, and others in diagnostic applications.

Different Types of Nanomedicine

A comparatively recent area of research and development, termed nanotechnology, has produced creative solutions for numerous medical problems. The term “nanomedicine” refers to the combination of its uses in illness screening, diagnosis, and treatment. This is an emerging discipline that could transform the entire healthcare system [9]. While particles between 1 and 100 nm in size are traditionally referred to as being in the nanomaterial’s domain, those smaller than one μm are also sometimes recognized. The main target of these nanomaterials is to contribute at the molecular level in the pharmaceutical as well as medical fields [10]. Nanomedicines provide better therapeutic activity by improving target specificity, pharmacokinetic parameters, and minimizing side effects by enabling the delivery of lesser amount of dose with high effectiveness [11].

Nanoparticles: Nanoparticles refer to tiny particles having exterior diameters ranging from 1-100nm. Various methods can be employed for the preparation of nanoparticles, such as hydrothermal synthesis, chemical reduction, coprecipitation, seeding, microemulsion, and son electrodeposition [12]. The energy levels of atoms present on the surface significantly influence the characteristics of nanoparticles, such as electromagnetism, optical properties, *etc.*, because they have a far larger surface-to-mass proportion than conventional materials. Due to these special qualities, nanoparticles are very desirable for multiple applications, such as medical fields, solar power, petroleum, and electrical power storage, *etc*. (Fig. **1**) [13].

2D Materials: A variety of self-supporting, membrane-like nanomaterials with a significant diagonal shape to thickness proportion are known as 2D [two-dimensional] materials. The two-dimensional nanomaterials are a family of laminated materials that are extremely fine and have a linear, distinctly anisotropic design. Two-dimensional nanomaterials with linear texture have strong activity, a high surface-to-volume ratio, superior mechanical qualities, and intrinsic optical activity that makes them suitable for a range of biological applications [14]. In general, two-dimensional nanoparticles can be divided into three main groups: inorganic, organic, and hybrid. 2D nanomaterials provide a distinctive connection for nano- and micro-range systems by binding with cells at

CHAPTER 5

Nanomedicine for Conjugated Therapy and Diagnosis in Cancer Treatment

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Abstract: Cancer remains a leading cause of mortality worldwide, necessitating continuous innovation in its diagnosis and treatment. Traditional therapies, including chemotherapy and radiotherapy, face significant limitations such as systemic toxicity, poor selectivity, and drug resistance. Nanomedicine has emerged as a transformative strategy that integrates diagnosis and therapy (theranostics) within a single nanoplatform, enabling targeted drug delivery, stimuli-responsive controlled release of payload, multimodal therapy, and real-time treatment monitoring. This chapter reviews the evolution and applications of various nanomedicine modalities, including polymeric nanoparticles, lipid-based carriers, metallic and silica-based nanoparticles, quantum dots, and Prussian blue nanoparticles, among others. It explores their mechanism of action through both passive and active targeting strategies, discusses the integration of multimodal therapeutic functionalities, and addresses the challenges related to the tumor microenvironment, immune interactions, and clinical translation. Through an analysis of recent advancements and clinical evaluations, this chapter provides a comprehensive understanding of how nanomedicine is redefining cancer care and outlines the prospects and limitations for its widespread implementation in personalized oncology.

Keywords: Active and Passive Targeting, Clinical Translation, Multimodal Theranostics, Personalized Oncology, Stimuli-responsive Release.

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INTRODUCTION

Cancer is a major global health concern, responsible for approximately 19.3 million new cases and 10.0 million deaths annually [1]. Its rising incidence and mortality rates pose a substantial challenge to increasing life expectancy worldwide. Although developed nations have experienced gradual improvements in cancer-survival rates due to advances in tumor biology, diagnostic innovations, and therapeutic strategies, the overall disease burden remains significant [2]. Addressing these growing challenges requires innovative approaches, continuous advancements, and optimized implementation of current cancer management strategies. Traditional cancer therapies, including chemotherapy, radiotherapy, and surgery, remain the basis of treatment, often used in combination to manage malignancies. Surgery remains essential for localized solid tumors, while systemic therapies are crucial to address metastatic conditions [3]. Radiotherapy is also a key modality in cancer care. However, its associated acute and long-term toxicities present substantial limitations [4]. Similarly, conventional chemotherapy faces obstacles such as drug instability, poor solubility, resistance, systemic toxicity, and collateral tissue damage [5]. Nanomedicine has revolutionized the field of drug delivery and therapeutics by offering innovative solutions to overcome the limitations of conventional therapies. By leveraging the unique properties of nanoplatforms, they provide intrinsic theranostic capabilities-combining enhanced precision, targeted delivery, and controlled release of therapeutic agents. These nanoplatforms can mitigate challenges such as poor drug solubility, rapid clearance, and systemic toxicity, leading to more effective and safer treatment outcomes [6]. A key advantage of nanomedicine lies in its ability to exploit the Enhanced Permeability and Retention (EPR) effect, which allows preferential accumulation in tumor tissues [7]. However, passive targeting alone is often insufficient due to physiological barriers and tumor heterogeneity [8]. To address these limitations, advanced nanomedicine designs now incorporate active targeting, stimuli-responsive approaches, and multifunctional capabilities to improve theranostic outcomes. Recent advancements in nanotechnologies emphasize the integration of diagnosis and therapy, co-delivery of multiple therapeutic agents, and responsiveness to tumor microenvironmental or external stimuli in a single nanoplatform. Multifunctional nanomedicine that combines these features holds immense potential for treating cancer. They not only improve drug efficacy and safety profiles but also enable real-time monitoring of therapeutic responses, paving the way toward truly personalized medicine.

This chapter explores the evolution of nanomedicine systems, focusing on their applications in overcoming current challenges in conventional cancer treatment (Fig. **1**). A special emphasis is placed on highlighting the recent advances of each type of nanomedicine in cancer clinical care, including upconversion nanoparticles, plasmonic nanoparticles, magnetic nanoparticles, quantum dots, carbon nanoparticles, prussian blue nanoparticles, mesoporous silica nanoparticles, lipid-based nanocarriers, and polymeric nanoparticles. Finally, the prospects and challenges of nanomedicine in clinical care are outlined.

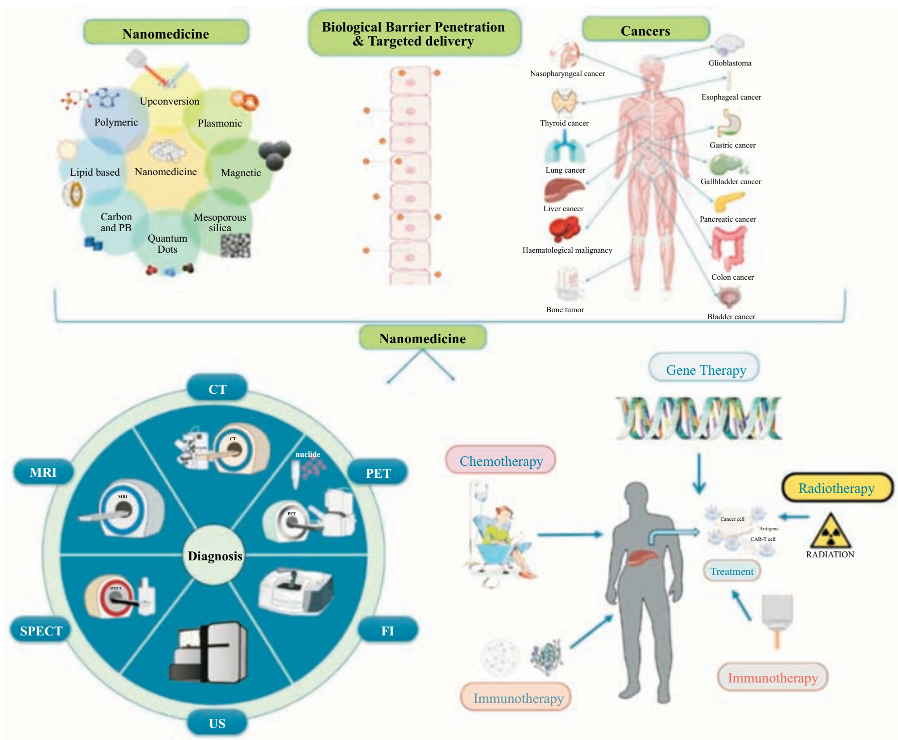

Fig. (1). Schematic representation of various types of nanomedicine used in multimodal targeted cancer theranostic applications.

KEY PRINCIPLES OF NANOMEDICINE

The introduction of nanomedicine for cancer therapy is motivated by the shortcomings of the traditional treatment methods and the transformative promise of nanotechnology-based approaches.

Requirement of Nanomedicine

Limitations of Conventional Cancer Treatments

Cancer treatment has traditionally relied on surgery, chemotherapy, radiotherapy, and immunotherapy. While these therapeutic approaches have significantly improved survival rates, they come with notable limitations. Chemotherapeutic

CHAPTER 6

An Efficient Machine Learning-based Approach to Detect the Alzheimer's Disease

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Abstract: The primary reason behind dementia, which is distinguished by a decrease in cognition, freedom within everyday tasks, is Alzheimer's Disease (AD), a disorder that causes brain cells to deteriorate. AD is addressed as a complex illness, with the cholinergic and amyloid hypotheses proposed as two primary theories underlying its pathology.. Additionally, a number of risk factors, such as aging, genetics, head trauma, vascular disease, pollution, as well as environmental elements, all participate in the illness. In this chapter, we have presented machine learning-based automatic identification of Alzheimer's Disease (AD). As features, Socioeconomic Status, Mini-Mental State Examination, Estimated total intracranial volume, Normalized whole-brain volume, and the Clinical Dementia Rating have been used. For classification, the KNN classifier has been used with different distance metrics and by varying the number of K-values. Here are mainly three types of distance metrics: Euclidean distance, Manhattan distance, and Minkowski distance, among others, to compute the performance measures of Accuracy, Recall, Precision, and F1-values.

Keywords: Alzheimer's disease, Accuracy, F1-values, Euclidean distance, KNN classifier, Machine learning, Manhattan distance,minkowski distance, Precision, Recall.

INTRODUCTION

A considerable reduction in cognitive function that affects an individual's capacity to carry out daily tasks is referred to as dementia. More than two-thirds of dementia cases in those 65 years of age and older are caused by AD, a neurological illness that gradually impairs both mental and behavioral abilities. Recall, understanding, language, focus, logic, and verdict are some of these abilities. Although AA does not directly cause mortality, it does significantly

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increase a person's susceptibility to additional issues that may ultimately result in death. Information from the Centers for Disease Control and Prevention shows that in 2022, AD will rank as the seventh most frequent cause of death in the US, with COVID-19 coming in at number one. After a stroke, AD was the sixth most common cause of death prior to the COVID-19 pandemic. AD is dementia's most prevalent type, and it is defined as developing neurodegenerative illness that is triggered by an accumulation of amyloid-beta peptide (Aβ) in the damaged areas of the brain, medial temporal lobe and neocortical frameworks. This form of dementia is characterized by the presence of neuritic plaques and neurofibrillary tangles [1]. Late-onset Alzheimer's Disease (LOAD) is the term used to describe AD, which usually appears after the age of 65. About 5% of AD patients have Early-onset Alzheimer's disease (EOAD), which is less prevalent and occurs before the age of 65. The symptoms of EOAD are frequently unusual, and the condition is typically diagnosed later, which causes the illness to progress more quickly [2]. Over the last decade, substantial developments have been made in creating biomarkers for the specific and early identification of AD. Cerebrospinal Fluid (CSF), plasma markers including phospho-tau, tau, and amyloid levels, and neuroimaging markers from amyloid and tau PET scans are examples of these biomarkers [3]. While there is no known remedy for AD, there are helpful therapies for control and lessening some of its symptoms. With the identification of novel disease biomarkers, the development of drugs intended to slow the disease's course has advanced significantly in recent years [3].

The manifestation of AD can differ according to the illness's stage. Depending on how much cognitive impairment there is and disability that each person experiences, AD is divided into several phases. The progression of Alzheimer's disease includes the preclinical (or presymptomatic) stage, moderate cognitive impairment, and dementia [4]. Dementia itself is further classified into three stages: mild, moderate, and severe.

The diagnostic standards contained in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) for AD differ from this staging method [5].

Following these initial indicators of cognitive decline are visuospatial impairment and linguistic disorders. In the intermediate to advanced phases, neuropsychiatric symptoms like disinhibition, agitation, wandering, psychosis, and apathy are also common. Late-stage symptoms include dyspraxia, difficulties with learning motor tasks, olfactory dysfunction, sleep difficulties, and extrapyramidal motor indications like dystonia, akathisia, and Parkinsonian symptoms. This is followed by incontinence, primitive reflexes, and complete reliance on caregivers [6 - 8].

A common AD patient's first and most frequently presenting symptom is episodic short-term memory loss. People might find it challenging to remember new information while still recalling long-term memories. Short-term memory loss may give rise to deficits in judgment, problem-solving abilities, executive functioning, and organizational skills. Tasks requiring abstract thought and multitasking may be difficult for them. Executive functioning deficits can range from mild to severe in the initial phases of the disease. Relatively early in their dementia, essential daily activities such as operating a vehicle, managing money, cooking, and meticulously organizing tasks are impacted [4].

When Alois Alzheimer looked into the brain of his first patient, who had memory loss and a personality shift before expiration, he observed amyloid plaques and an enormous neuronal loss. He described the state of the patient as an awful illness affecting the brain cortex. In his psychiatric manual, the 8th version, Emil Kraepelin 1st referred to this neurological clutter as AD. Cerebral problems such as AD or additional illnesses such as infections, intoxications, anomalies within the circulatory and pulmonary systems, which lower the oxygen content reaching the brain, malnutrition, low vitamin B12, tumors, and additionally more can all lead to an increasing cognitive decline [5]. Currently, there are roughly 50 million AD patients worldwide. By 2050, the total number is anticipated to have doubled every 5 years to 152 million. The burden of AD affects people, the economy, and their families; the annual worldwide expenses are estimated to be $1 trillion. AD, as of right, has no known treatment; nevertheless, there exist treatments that can aid in symptom relief [7]. This evaluation aims to provide a concise summary of AD pathology, investigation, causes, and current treatments. It additionally emphasizes the discovery of novel compounds that target numerous pathogenic mechanisms, such as tau and Aβ aggregation, inflammation, oxidative damage, misfolding, and others, and may be used to treat or prevent AD.

In addition to a medical and family history review, a patient suspected of having AA should undergo various examinations, including a neurological test, Magnetic Resonance Imaging (MRI) of the brain, laboratory testing for vitamin B12, and other diagnostic tests [8]. Due to specific research, vitamin B12 deficiency has been associated with neurologic problems as well as increased chances of AD. High levels of homocysteine are a distinctive sign of vitamin B12 deficiency and can lead to brain injury *via* oxidative damage, enhanced calcium influx, and cell death. Serum vitamin B12 levels, whole blood counts, additionally serum homocysteine levels can all be evaluated to identify inadequate vitamin B12 [9 - 11]. The AD, Related Disorders Association (ADRDA), and the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) created the study group NIDCS-ADRD in 1984 to develop clinical diagnostic standards for AD. Criteria for diagnosing AD comprise the following: (1) dementia, that is

CHAPTER 7

Artificial Intelligence in Drug Delivery: An Alternative Approach to Traditional Nano-Theranostic Systems

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Abstract: Nanomaterials have been extensively investigated to be used in clinical and pharmaceutical applications due to their unique features, such as shape, size, surface properties, reactive oxygen species (ROS) scavenging, targeted drug delivery, improved cell imaging due to excellent fluorescence property, precise personalized diagnosis, reduced side effects, and excellent sensing property. Despite all advantages, nanomaterials are signified as a potential generator of ROS, a symbol of toxicity. Although some clinical practices utilize ROS to prevent cancer, bacterial infection, *etc*., non-customized morphology can yield excessive ROS that may cause harm to normal cells. Another disadvantage is the infant research stages; more modulation in design is needed, and evaluation, as well as validation in nanotoxicity, is required. Although there exist a few stories of nano-medicine-mediated theranostic applications, the emerging challenges are increasingly prompting researchers to explore the optimal use of artificial intelligence (AI) in designing personalized drug delivery systems, potentially offering a more effective alternative to traditional nano-theranostic approaches. Accordingly, an elaborate governance framework is needed to develop and implement innovative AI systems successfully in the healthcare sector. The present work provides a comprehensive overview of the role of AI technologies in drug delivery, along with its ethical and regulatory concerns. Additionally, it illuminates the numerous challenges met in the employment of AI systems in clinical practice.

Keywords: Artificial intelligence in drug delivery, AI bot, Drug discovery, Drug delivery, NLP, Toxicity profile.

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Soumik Podder & Amalesh Samanta (Eds.)

INTRODUCTION

Drug

The word ‘drug’ is derived from the French word ‘drogue’, meaning ‘dry herb’. The use of medicines dates back to ancient civilizations, making it nearly impossible to identify the very first person responsible for drug discovery. Early written records of medicinal drugs are known to have existed in a range of cultures, including Greek, Egyptian, Chinese, and Indian civilizations. This strongly suggests that ancient people treated diseases with conventional methods, most of them involving plants, while others involving animal products and minerals. Chinese medicine, Ayurveda, and the traditional Greek approaches are also proof of plant-based treatment. The positive fact is that those medicines have minimal or negligible side effects [1].

Both Arabic and European countries studied drugs in the medieval era. No sooner than the renaissance in the 19^{th} century, the pharmaceutical approach made its appearance in the pre-modern era. Chemicals were discovered and tested actively in clinical research. It started as an attempt to reduce the load on rare medicinal herbs [1].

With the advancement of technology and the discovery of various viruses, bacteria, and disease-causing microbes, pharmaceutics played an important role in combating them and saving human lives as much as possible [2]. Antiseptics, vaccines, and anesthetics were slowly and steadily brought into existence. More elements were explored by mixtures and mutations to create recreational drugs. At present, both medicinal as well as recreational drugs have become major worldwide industries [3].

Thus, modern drugs are a combination of various chemical components. Any edible substance other than food, which causes changes in mood, hormones, behavior, thoughts, or feelings, can be referred to as a drug [4]. They are essentially used to prevent or suppress existing diseases, infections, abnormal behavior, or other symptoms. Other than treatment and diagnosis, these doses play an instrumental role in the functioning of the brain, glands, and various organs. Such pharmaceutical amalgams also play a significant role in reducing stress, anxiety, pressure levels, and many more physical and mental conditions. However, drugs, such as opioids, are highly addictive and harmful to human health [3].

Traditional methods of designing medicines have recently been replaced by CADD (computer-aided drug design). It refurbishes design techniques and also helps normalize the time taken in drug discovery. AI-based technology can be highly utilized in every process of drug formulation, thus aiding in reducing health hazards and fatalities associated with pre-clinical trials. AI, recognized as an efficient tool for data mining, can easily deal with the bulky pharmacological data and machine learning (ML) processes in every formulation step. AI possesses the ability to optimize all the operations associated with each step, such as improving quality control (QC) and the critical parameters, as well as increasing production by many folds without any hassle, hence upgrading the pharmaceutical industry.

Drugs are segregated into different types and forms, which are listed below.

On the Basis of Administration [5]

- **Oral route:** It is the safest and most common way of drug administration. The drugs are ingested directly as and flow into the human stomach before the action commences.
  - Liquids
  - Capsules
  - Tablets
  - Chewable tablets
  - Suspensions
- **Injection route:** These drugs are administered directly into the skin through any of the following approaches, *via* a needle and syringe, depending upon the affected area (Fig. **1**).
  - Subcutaneous layer (skin)
  - Intramuscular layer (in muscles)
  - Intravenous layer (in veins)
  - Intrathecal layer (around the spinal cord)

- **Sublingually and buccally:** Some doses are placed under the tongue or between teeth and gums for absorption.
- **Vaginal route:** The drugs are administered vaginally to women to combat infections and relieve symptoms during menopause in the form of
  - Cream
  - Solution
  - Tablet
  - Gel
  - Suppository
- **Ocular way:** This way of drug administration is used to treat optical diseases by applying the drugs in or around the eyes. The drugs are in the form of
  - Liquid (drops)
  - Gel

CHAPTER 8

Artificial Intelligence in Nanomedicine Formulation and Applications

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Abstract: Artificial intelligence is emerging as a transformative factor in the development of nanomedicine—the integration of nanotechnology and biomedical science to solve complex health problems. This paper reports on the synergistic integration of AI and nanomedicine, with a focus on the contributions it makes towards creating nanoscale materials, upgrading nanomaterials, and applications in diagnostics, drug delivery, and regenerative therapy. AI-driven approaches rapidly identify the ideal properties of nanomaterials, enhance the interaction between drugs and nanoparticles, and improve the accuracy of their mechanism for targeting diseases. Here, predictive modeling using machine learning algorithms accelerates progress in nanocarriers, nanosensors, and imaging technologies, while providing an opportunity to detect diseases at early stages and customize targeted therapeutic strategies [1].

The article highlights revolutionary breakthroughs enabled by AI in addressing the aforementioned limitations of nanomedicine, specifically in terms of production scales, regulatory burdens, and nano-material toxicity. Case studies illustrating AI-driven breakthroughs in treatments for cancer, cardiovascular diseases, and neurological disorders describe improved clinical results through targeted and advanced diagnostics and treatments. However, the convergence of AI and nanomedicine also raises ethical, regulatory, and data-related issues that require interdisciplinary collaboration and robust frameworks for responsible implementation. This study highlights the potential of AI in transforming nanomedicine, paving the way for next-generation medical solutions that are more secure, efficient, and tailored to meet the unique needs of patients. By connecting computational technologies with biomedical applications, the research envisions a future in which AI-driven nanomedicine revolutionizes healthcare delivery worldwide [2].

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Keywords: Artificial intelligence, Drug delivery systems, Deep learning, Machine learning, Nanosensors, Nanomedicine, Nanotechnology, Personalized medicine, Predictive modeling, Targeted therapy.

INTRODUCTION

Overview of Nanomedicine

Nanomedicine is a rapidly emerging field that combines nanotechnology with healthcare to identify and prevent diseases at the molecular level. Nanomedicine provides unique opportunities to enhance therapeutic effectiveness and facilitate precision medicine. Nanoparticles, nanosensors, and drug delivery systems are essential elements that have transformed fields such as oncology, infectious diseases, and regenerative medicine [3]. Nanomedicine utilizes physical and chemical characteristics that develop at the nanometer scale, ranging from 1 to 100 nanometers in diameter. Nanotechnology advancements have enabled the development of biocompatible nanoparticles, including liposomes, dendrimers, and polymeric micelles, which can be tailored for targeted drug delivery and focused therapies. Nanomedicine has experienced significant advancements in creating nanosensors that can detect biomarkers at extremely low levels, thereby facilitating the early detection and monitoring of diseases. A major obstacle to nanomedicine is the scalability of production, regulatory issues, and the potential toxicity of nanomaterials. These issues necessitate a multidisciplinary strategy that incorporates material science, biology, and computational methods. Artificial Intelligence stands out as a vital facilitator in addressing these problems, promoting innovation, and accelerating the progress of nanomedical solutions [3].

The Function of Artificial Intelligence in Contemporary Healthcare

Artificial Intelligence has emerged as a revolutionary influence in the modern healthcare system. It enhances the system by leveraging machine learning, deep learning, and data analysis to improve patient outcomes. AI enhances diagnostic precision, predicts treatment responses, and streamlines complex workflows. It is applied from medical imaging and tailored healthcare to predictive analytics and robotic surgery. AI offers solutions for complex issues, including molecular modeling, nanomaterial production, and precision medicine, such as precision drug delivery. AI is transforming the healthcare sector by enabling informed decisions through data analysis. Machine learning algorithms examine large volumes of clinical data, revealing patterns and insights that may be missed by human analysis. AI-based diagnostic systems have enhanced medical imaging, demonstrating higher accuracy in identifying conditions such as cancer, heart disease, and neurological disorders [4]. These systems minimize diagnostic errors and help healthcare providers make informed decisions. In nanomedicine, AI aids in the development and enhancement of nanomaterials by anticipating their physicochemical characteristics and interactions with biological systems. For example, AI models can replicate the behavior of nanoparticles within the human body, enabling the optimization of their size, shape, and surface characteristics for improved therapeutic outcomes. Additionally, AI-powered platforms facilitate the high-throughput evaluation of nanomaterials, thereby accelerating the discovery of candidates with ideal characteristics for drug delivery and various applications [4].

Significance of AI in Nanomedicine Development and Uses

The development of AI and nanomedicine has created new opportunities for innovation. AI-based methods facilitate the creation and enhancement of nanocarriers, predictive modeling of drug-nanoparticle interactions, and effective examination of extensive datasets from clinical trials. AI accelerates the identification of new nanomaterials and enhances the accuracy of treatment methods. This section focuses on the capability of AI to address current challenges in nanomedicine and facilitate its transition from laboratory to clinical application. The capability of AI to analyze and process intricate datasets is especially beneficial in nanomedicine. Conventional experimental methods for designing and testing nanoparticles can be laborious and costly [5]. AI algorithms can easily analyze data from high-throughput experiments, recognizing patterns and correlations that guide the development of more efficient nanocarriers. AI can forecast the optimal arrangement of nanoparticles for precise drug delivery, thereby minimizing the need for extensive trial-and-error testing. Predictive modeling is another field in which AI performs exceptionally good. Machine learning models are capable of predicting how nanomaterials interact with biological systems, taking into account aspects such as biodistribution, cellular uptake, and toxicity. These forecasts enable scientists to develop nanomaterials with enhanced safety and effectiveness characteristics, thereby reducing potential risks to patients. Moreover, AI-based evaluation of clinical trial data helps pinpoint elements that affect treatment outcomes, guiding the development of tailored nanomedicine approaches. AI plays a crucial role in enhancing diagnostics in nanomedicine. Researchers have created systems that can detect diseases early with high sensitivity and specificity by combining AI with nanosensors and imaging technologies. For example, nanosensors augmented with AI can instantly evaluate biomarker information, facilitating quick diagnosis and tracking of conditions such as cancer, Alzheimer’s, and infectious diseases [5].

SUBJECT INDEX

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This book presents a lucid and current examination of nanobiomedicine and its progress driven by artificial intelligence. Featuring comprehensive discourse on foundational principles, theranostic uses, and ethical dimensions, it constitutes an indispensable compendium for both investigators and practitioners. The work's interdisciplinary perspective and clinical applicability render it requisite reading for prognosticating the trajectory of medical care.

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