# NANOMATERIALS IN BIOLOGICAL MILIEU:

## BIOMEDICAL APPLICATIONS AND ENVIRONMENTAL SUSTAINABILITY

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**Bentham Books**

# Nanomaterials in Biological Milieu: Biomedical Applications and Environmental Sustainability

Edited by

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**Nanomaterials in Biological Milieu: Biomedical Applications and Environmental Sustainability**

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ISBN (Online): 978-981-5313-26-0

ISBN (Print): 978-981-5313-27-7

ISBN (Paperback): 978-981-5313-28-4



First published in 2025.

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# PREFACE

Inside the biological milieu, nanomaterials come in myriad shapes and sizes and interact with various biomolecules, forming a bio-nano interface. The fate of both nanomaterial and biomolecule depends on the type of interaction at the bio-nano interface. Tremendous research on the bio-nano interface has led to the development of nanomaterials based on various products and applications in biomedical science. In view of the above discussion, this book intends to discuss the interactions of nanomaterials with different biomolecules and the consequences of this interaction in the field of biomedical science. Hence, the book will initially discuss the current state-of-the-art techniques for various nanomaterial formulations. The later chapters of the book will discuss the potential applications of nanomaterials in biomedical sciences and environmental sustainability. The book is a contribution of experts from microbiology, cancer biology, pharmaceutical science, nanotechnology, plant biotechnology, and environmental sciences. The book will discuss some novel applications of nanomaterials in the field of biomedical and environment.

The book, in total, comprises 11 chapters written by experts working in the respective aspects of nanotechnology. For instance, Chapters 1, 2 and 3 describe various methods for the synthesis of nanomaterials for different applications. Chapter 4 describes the roles of nanomaterials in various disease diagnosis. The applications of nanomaterials in various biomedical sectors are discussed in Chapters 5, 6, and 7. Chapters 8 discuss the application of nanomaterials in cancer therapy. Chapter 9 interprets artificial intelligence and nanotechnology-integrated recent applications in early lung cancer detection and therapy. Various environmental applications of nanomaterials are discussed in Chapters 10 and 11.

We are very much thankful to all the contributing authors for their timely cooperation and support, without which this book would not have taken its final shape. We are also thankful to the series editors for their critical reviews and positive remarks that brought positive developments to the book.

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CHAPTER 1

# The Current State-of-the-Art Technique of Nanomaterial Fabrication

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**Abstract:** Nanomaterials are the finest materials that are being used in frontline research for their unique properties and potential applications in different fields, including medicine, electronics, and energy. To take advantage of these properties, the fabrication of nanomaterials provides a key resource with greater biocompatibility in reliable forms. In recent years, numerous advances in nanomaterial fabrication have made it possible to use them in different fields for precise control of material properties. However, there are still many challenges that need to be addressed to unlock the potential of nanomaterials. This book chapter will provide a brief overview of the challenges associated with nanomaterial fabrication and the potential future applications for them. The chapter will begin by discussing the different nanomaterial fabrication techniques, including physical, chemical, and biological approaches, as well as their advantages and disadvantages. Hereinafter, the chapter will also explicitly explore the growth of research into nanomaterial fabrication, including recent advances in the field and their potential applications for the future development of nanomaterials.

**Keywords:** Biocompatibility, Biological advantages, Nanofabrication, Nanoparticles.

## INTRODUCTION

Fabrication has played a key role in human history since the dawn of time. The invention of man-made tools has enabled a better understanding of fabrication and predictions of advancements in nanomaterials. Raw materials used in the past had unknowingly served various purposes thousands of years ago. However, around

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4500 years ago, these materials were employed to fortify ceramic mixtures and utilized in nanoform for different functions [1]. As time has passed, the evaluation of nanomaterials has grown quicker and has been implemented in various sectors, but their use has been limited to a certain extent. Our advanced technology has made it possible to use these nanomaterials in a new and directed way. To explore newer forms of these nanomaterials, fabrication has made it possible to create artifacts on a nanoscale, giving a new perspective to our modern civilization. Although the fabrication of nanostructures with minimal dimensions has provided us with a great degree of precision in terms of material composition, it has also enabled the development of highly functional devices that are no more than 100 nm in size [2, 3]. This has led to a rapid increase in knowledge and a greater understanding of the characteristics of many nanostructures and their associated applications. Examples of these devices include solar cells [4], LEDs [5], laser diodes [6], hard drives [7, 8], self-cleaning handwash [9, 10], antibacterial materials for skin protection [11, 12], food preservation [13], *etc*.

These features are employed in hybridizing engineering fabrication processes with chemistry and biology to create new fabrication methods. With the right approach, nanoscale materials with bulk- and molecular-level features can be designed, manufactured, and integrated into functional devices [14]. This potential advancement in modern nanofabrication techniques is thought to be of great benefit in many areas. To make this possible, engineering nanofabrication approaches must be refined to manipulate the structural, mechanical, optical, and magnetic or electronic properties of the materials being processed [15]. This can be done through two main categories of nanofabrication: top-down [16] and bottom-up [17]. Top-down fabrication relies on molecular processing to produce atomically precise materials in bulk and at low cost. With this approach, a broad range of materials from both wafer and thin-film sources can be accessed [18 - 21]. Top-down fabrication is also used to manufacture devices with the desired shape and characteristics, such as cell sorting platforms, bead assemblies, biochemical sensors, and drug testing platforms [22 - 25]. Bottom-up nano-fabrication, on the other hand, makes and uses complex nanoscale assemblies and guided self-assemblies into different shapes and materials, like nanowires and nanotubes with multiple organic and inorganic elements [15].

Overall, this book chapter provides an overview of nanofabrication methods for the production of highly functional and structurally complex nanostructures with an emphasis on large-scale nanomanufacturing (Fig. **1**). Moreover, this chapter provides a deep insight into the fundamentals of synthesis methods and the potential opportunities associated with the broad and exciting area of nanomaterials.

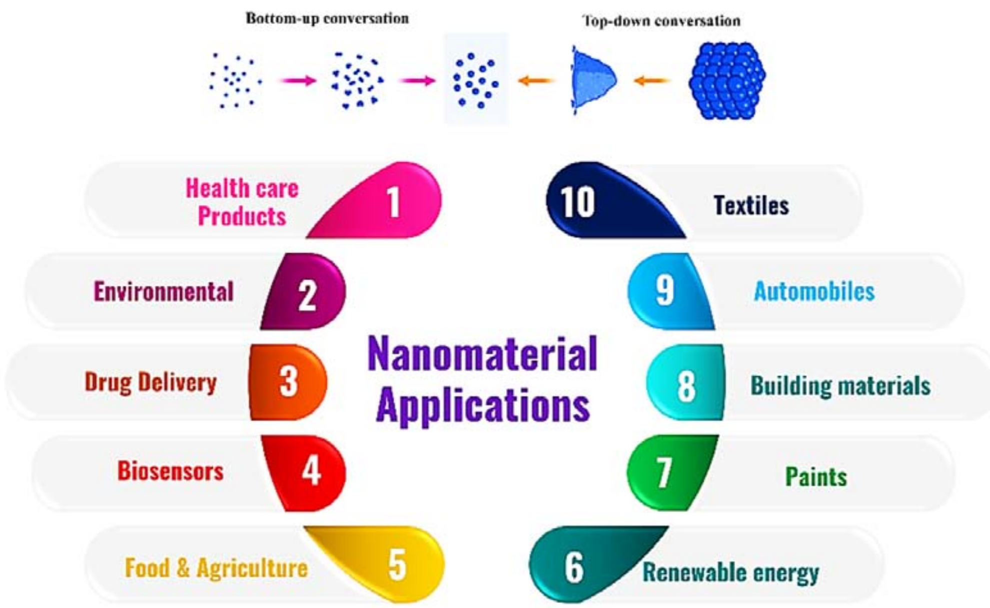


**Fig. (1).** Overview of nanomaterial fabrication with its applications.

## DIFFERENT FORMS OF NANOMATERIALS

Different methods can be used to synthesize nanomaterials, such as carbon fullerenes using helium or neon atmosphere to generate an arc [26], carbon nanotubes through carbon-arc discharge, laser ablation of carbon, or chemical vapor deposition [27]. Fabrication of metals can be produced by different methods, including combustion synthesis, pyrolysis, mechanochemical

## CHAPTER 2

# Recent Advances and Future Perspective in Green Synthesis of Nanomaterial for Healthcare Management

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**Abstract:** Nanotechnology, which operates on the 1 to 100 nanometer scale and has a wide range of applications in medicine and pharmaceuticals, has grown rapidly in recent years. Nanomaterials, with their distinct features, hold great promise for cancer treatment due to their low side effects and faster healing potential. However, traditional techniques for producing nanomaterials have drawbacks such as high costs, energy usage, and environmental hazards. To address these concerns, researchers have turned to green nanotechnology, which aims to reduce potential risks associated with traditional production methods. Green nanoparticles, synthesized using environmentally friendly procedures, provide a sustainable solution with reduced energy consumption and non-toxic byproducts. They can be produced using a variety of natural sources such as bacteria, fungi, algae, and plant components. The green method has shown a variety of therapeutic effects, including antiviral, antioxidant, and anticancer qualities. It promotes efficient oral cancer treatment through precise drug administration, thereby reducing side effects. Furthermore, the green synthesis process causes the production of reactive oxygen species (ROS) and free radicals, which promotes apoptosis in cancer cells. This chapter discusses an overview of recent developments in green nanomaterials, their synthesis process, and healthcare management.

**Keywords:** Apoptosis, Biocompatibility, Diagnostics, Environment friendly, Green synthesis, Metallic nanoparticles, Nontoxic, Nanoparticles, Therapeutics, Targeted drug delivery.

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## INTRODUCTION

Nanotechnology, with nanosizes ranging from 1 to 100 nm, has marked the beginning of an era in the healthcare sector, assisting in both disease detection and management. It is the most critical area of research in the early twenty-first century. Nanotechnology has improved healthcare and sparked the development of groundbreaking nanosystems for the detection, imaging, and therapy of numerous diseases, including cancer, heart disorders, and diseases linked to the central nervous system [1]. Due to their high surface-to-volume ratio, nanoparticles are ideal carriers for many clinical applications [2]. Nanomedicine, which combines modern biology and medicine, is creating a new benchmark for disease prevention and treatment in the pharmaceutical industry [3]. By building smart devices that can aid in disease detection at an early stage, nanomedicine is recognized to be efficient against *in vitro* and *in vivo* diagnostics [4]. The most cutting-edge interdisciplinary area of nanotechnology in recent years is known as regenerative medicine, which is capable of delivering medications and hormones for tissue healing [5]. Nanosensors can measure the concentration of sodium, glucose, cholesterol, cancer biomarkers, and other infectious agents. Advances in nanotechnology raise the chances of invasively and precisely delivering drugs to the desired sites [6]. Nanomaterials have unique physical, chemical, and biological capabilities due to their small size, which increases strength, reactivity, and conductivity. They are important in a variety of sectors such as they can be applied to targeted medication delivery, diagnostics, and tissue engineering, used for water purification and air filtration, and are necessary for effective energy storage devices, sensors, and renewable energy technologies such as solar and fuel cells [7]. Hepatobiliary disorders affect over 2 million people each year, and inefficient medication delivery systems typically prevent therapy. Nanotechnology provides an appropriate strategy by allowing customized medicine delivery to the liver while using its unique properties. Surface modification improves medication delivery effectiveness and reduces side effects using a variety of nanomaterials, including polymer, inorganic, and multifunctional nanoparticles. However, toxicity and stability difficulties exist, which may cause inflammation and protein adsorption. Current studies in nanotechnology have become essential for developing targeted treatments for liver ailments [8]. Nanobiomaterials have significance in cardiovascular applications since they improve therapy effectiveness and patient outcomes by delivering drugs more precisely and with fewer adverse effects. Their large surface area-to-volume ratios facilitate interactions with biological molecules, hence improving diagnostic and therapeutic capacities [9].

Nanotechnology can be synthesized using several chemical methods. However, these methods use toxic and expensive solvents, producing toxic and lethal end products. Thus, there is an urge to develop an eco-friendly approach to overcome these drawbacks [10].

Green nanotechnology, developed by biological methods, has recently gained popularity in the healthcare industry. It is an environmentally friendly and biocompatible method that leads to large-scale production with few hazardous side effects [11]. The greener method of nanoparticle synthesis is mostly used in nanomedicines and nano-drug delivery systems. Furthermore, green approaches are thought to reduce the risks of the production of noxious intermediates and by-products because they are inexpensive and have few complications. Two major aspects of green synthesized nanomaterials involve [12]:

- Developing nanomaterials that will address environmental issues.
- Developing nanomaterials to reduce any negative effects on human health.

A comprehensive and fundamental literature review was conducted to discover the recent advances and advantages of green-synthesized nanoparticles. Several online databases were evaluated, such as Scopus, PubMed, NCBI, and Google Scholar, between the years 2000 and 2022 with the keywords “nanoparticles”, “green synthesis”, “therapeutics”, “diagnostics”, and “targeted drug delivery”.

## SYNTHESIS OF NANOMATERIALS

Several chemical processes can be used to synthesize the nanoparticles. Some of them include:

### Chemical Precipitation Method

This method involves converting a solution into a solid by either making it insoluble or extremely saturated. Chemical agents are added, and subsequently, the precipitates and solution are separated [13]. Chemical precipitation is the most common way for removing ionic metals from solutions, especially in industrial effluent contaminated with hazardous metals. Ionic metals are converted into insoluble particles *via* a chemical reaction involving soluble metal compounds and a precipitating agent. These particles are subsequently removed from the solution using filtration and settling methods [14] (Fig. **1**).

### Sol-gel Method

The sol-gel method is a chemical synthesis technique for producing nanomaterials. The two major steps in this process are condensation and hydrolysis. It begins with converting a liquid “sol” into a solid “gel” phase by various chemical reactions. Initially, precursor molecules are hydrolyzed and condensed, forming a colloidal suspension (sol). This sol then polymerizes to

# CHAPTER 3

# Biosynthesis of Selenium Nanoparticles and their Biological and Pharmaceutical Applications

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**Abstract:** Numerous methods have been established to fabricate nanoparticles with varying physico-chemical properties to suit the applications. However, because of eco-friendly, non-toxic, and cost-effective approaches, fabrication methods have attracted the interest of many research groups to synthesize different nanoparticles, especially for biological and pharmaceutical applications. In this context, microorganisms and plant extracts are widely utilized for the bio-fabrication of nanoparticles. Hence, this chapter intends to discuss the bio-fabrication of selenium nanoparticles and their biological applications. In this context, SeNPs have antioxidative, antimicrobial, and anticancer activities. Hence, SeNP has a broad range of therapeutic effects and is often used to treat various diseases, including diabetes, cancer, arthritis, *etc.* Selenium nanoparticles can be used for numerous pharmaceutical applications, such as gene and drug delivery. Additionally, SeNPs are used for environmental remediation and nano-biosensors, which can be used to detect pathogens, nucleic acids, antibodies, *etc.* To this end, the chapter will explore the potential of biological agents for the bio-fabrication of nanoparticles and their application in different pharmaceutical industries.

**Keywords:** Antimicrobial activity, Anticancer activity, Bio-fabrication, Nanoparticles, Selenium.

## INTRODUCTION

In the twenty-first century, nanotechnology has become an emerging field of science. In this context, the synthesis of nanoparticles using natural products is gaining importance, and they already have a variety of beneficial properties. There are various techniques to synthesize nanoparticles, such as physical, chemical, and biological approaches.

However, using chemical and physical methods to fabricate nanoparticles has disadvantages, such as the use of harmful substances that are not eco-friendly.

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Hence, biological/green synthetic approaches for nanoparticle synthesis have piqued the interest of several research groups since they are cleaner, have fewer side effects on the human body on application, and are non–toxic and eco-friendly in nature. Among the essential micronutrients necessary for humans and animals, selenium (Se) plays an important role. Although selenium comes in two forms—organic and inorganic—it has been shown that organic selenium compounds are more resilient than inorganic ones. It has been reported in various studies that selenium nanoparticles are a little toxic and highly bio-active; hence, they possess promising biomedical applications [1]. This chapter will briefly discuss the biological approach to synthesizing selenium nanoparticles and their pharmaceutical applications. Even though there are numerous techniques for the fabrication of selenium nanoparticles, biological methods using different biological agents, such as microbes, plant extracts, *etc.*, are attracting the interest of different scientific groups. The use of microorganisms for nanoparticle synthesis involves certain risks, such as pathogenicity, and necessitates the maintenance of massive cultures. As a result, the production of nanoparticles using plants and plant extracts is gaining popularity [2]. Furthermore, manufacturing of nanoparticles utilizing plants/some plant extracts has benefits over microorganisms such as bacteria, algae, fungus, and so on. Hence, green synthetic approaches are used for the synthesis of nanoparticles using plant products that are much simpler, eco-friendly, easily available, cost-effective, efficient, and can be scaled up easily for larger operations [2, 3]. Different nanoparticles, for example, zinc oxide, silver, gold, iron, and palladium, have been successfully synthesized using green synthetic approaches [2].

## NANOPARTICLES

Richard Feynman is known as the father of modern nanotechnology [4]. However, in 1925, the idea of a 'nanometer' was suggested by Nobel Laureate Richard Zsigmondy. In 1959, Richard Feynman presented a lecture named 'There's Plenty of Room at the Bottom', in which he addressed the concept of manipulating matter at the atomic level [4]. The word 'nanoparticle' was coined for the first time by Norio Taniguchi in 1974. A nanoparticle is usually described as a particle of matter sized between 1 and 100 nanometres in diameter [5]. Nanoscience is the study that helps in the construction, formation, composition, shape, and design of particle sizes between 1-100 nanometers [6]. When there is a comparison between the bulk or the large size of the same material and the nanoparticle, the nanoparticles show some advanced physicochemical features, such as tiny size and higher surface area to volume ratio, compared to bulk material [7]. Hence, nanoparticles are considered a bridge between bulk and small-sized materials onthe nanoscale. Nanoparticles usually comprise three layers: the core, surface layer, and the shell layer. Among them, the surface layer usually comprises a diversity of molecules named polymers, metal ions, and surfactants [8]. Nanoparticles are either an assembly of one material or a combination of more than one material [9]. Nanoparticles can either remain as suspensions, colloids, or dispersed aerosols mainly because of their electromagnetic properties and chemical composition [10]. In the past decades, the research on nanoparticles has opened many different and new opportunities for their use in the treatment of many complicated diseases. Due to their unique and extraordinary features, such as the tiny dimensions, higher surface area to volume ratio, surface chemistry, solubility, and multi-functionality, nanoparticles are marvelously special [11]. Nanoparticles manifest themselves as good candidates for drug transporters, achieving huge triumphs in delivering therapeutic molecules to specific target sites without any or fewer side effects. Nanoparticles synthesized using biological methods are being applied in different biomedical engineering fields, which is only due to their advanced physico-chemical properties [12]. Additionally, nanoparticle systems seem a favorable alternative to oral administration drug-delivering systems and nutritional supplementation.

## Selenium Nanoparticles

Selenium or Se is one of many vital microelements in the body because of its pro-oxidative and anti-oxidative effects. In 1817, Swedish scientist Jons Jacob Berzelius first discovered the element selenium [13]. The letter ‘Se’ in the word selenium was adopted from the word ‘selene’, which is the other name of the moon in the Greek language. It is presented as group 6 of the modern periodic table and holds an atomic number of 34 [13]. It is an indirect elemental semiconductor and has always attracted the interest of researchers due to its remarkable properties, such as photoelectrical properties, catalytic activities towards organic hydration and oxidation reactions, optical properties, *etc.*, and greater future application in different fields of biological sciences [14]. Hence, selenium is a partly solid non-metal, mostly seen as red in powder form, black in vitreous form, and metallic gray in crystalline form [15]. SeNP exhibits better biological activity when it enters into the circulation of the human body compared to other organic and inorganic selenium products [11]. However, selenium deficiency in our body can result in the degeneration of many organs and tissues, such as disorders related to heart muscle and joints, prostate cancer, thyroiditis, or asthma [16].

### *Synthesis of Nanoparticles*

Nanoparticles are of two types: naturally found and manmade. Nanoparticles are naturally available in volcanic ashes, ocean sprays, tiny sand particles, dust, and biological living organisms like viruses [17]. Manmade nanoparticles are also

**CHAPTER 4**

# The Roles of Nanomaterials in Disease Diagnosis

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**Abstract:** Nanotechnology is an interdisciplinary field of science that has revolutionized different fields of science and technology, agriculture, and medicine. Current clinical diagnostic methods are less sensitive, are unable to detect multiple analytes, and have adverse effects on the human body. Hence, there is a need for a diagnostic method that can detect the early onset of disease, conduct complete health checks, and offer a reliable pretext for effective treatment. Currently, many nanomaterials are produced to prevent, diagnose, and treat various diseases. There are a few nanomaterials, such as nanowires, nanotubes, nanocrystals, cantilevers, dendrimers, quantum dots, and liposomes. These materials are quite suitable and effective for imaging technologies for the highly specific detection of DNA and proteins. Nanomaterials are used to diagnose and treat a wide range of diseases, including communicable and non-communicable diseases. The main objectives of the current chapter are to introduce various nanomaterials and their applications in the diagnostics of different diseases that affect human life.

**Keywords:** Carbon nanotubes, Nanoparticle, Nanotechnology, Quantum dots.

## INTRODUCTION

Recently, a large number of nanotechnologies and nanomaterials have been discovered and utilized for numerous scientific applications owing to their outstanding physio-chemical properties. However, the applications of nanomaterials are very wide and include electronics, agriculture, biosciences, and science & technology, but health care and diagnostics are the most predominant areas where nano-materials are commonly used [1]. Nanomaterials possess highly diverse structural properties and, hence, perform versatile functions. Therefore, nanomaterials are multi-functional and provide a highly sensitive signal that is highly suitable for the imaging process. Nanomaterials are suitable candidates for use in diverse types of nanodevices used for qualitative and quantitative diagnostic purposes in humans and animals. Chemically, there are mainly three

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types of nanomaterials, namely, inorganic, organic, and hybrid nano-materials, which have been extensively studied and exploited in diagnostics and healthcare [1].

Carbon nanotubes, nanocrystals, liposomes, dendrimers, micelles, hyper-branched organic polymers, molecularly imprinted nanostructures, and polymeric hydrogel nanoparticles are the best examples of organic nanomaterials that have been widely used as imaging and therapeutic agents [2]. Inorganic nanomaterials such as quantum dots, superparamagnetic iron oxide nanoparticles, metallic nanoparticles, and metal oxides have also received considerable interest in healthcare diagnostics, particularly in biosensing and biosensor construction. Nanomaterials are exploited in diverse types of imaging technologies such as magnetic resonance imaging, positron emission tomography, computed tomography, single-photon emission tomography, optical imaging, and ultrasound imaging [3].

Nanomaterials possess special and exceptional properties that allow for a wide range of diagnostic approaches. Nanomaterials, for instance, may be used to alter surfaces in order to provide more binding sites for immobilized binding receptor molecules, thereby improving diagnostic effectiveness. Furthermore, illness biomarkers may be labeled with nanoparticles to enhance the sensitivity and specificity of bio-detection techniques used in diagnosis. Nanomaterials have revolutionized molecular diagnostics, point-of-care diagnosis, disease therapeutics, and personalized medicine. The incorporation of biomarker discovery into nanodevices, in addition to the modification and application of nanomaterials, has significantly improved clinical outcomes [4].

More recently, a wide range of biomarkers have been discovered to identify various diseases at the early stage of their onset or early occurrence in humans and animals. However, highly minute amounts of biomarkers from the range of nano to atto levels are present, and their detection in biological samples is an uphill task. Hence, highly sensitive nanomaterials that have very strong binding sites for immobilized binding receptor molecules and the early appearance of biomarkers in biological fluids are required. Consequently, biomarker discoveries made by using nanodevices and nanomaterial alterations will improve the detection of cancer, cardiovascular, infectious, and neurological illnesses. Nanomaterials offer help in the development of advanced molecular diagnostics, point-of-care diagnosis, disease care with treatments, and customized medicine. Hence, healthcare diagnostics will improve dramatically and lead to synergetic medicinal solutions using nanomaterial engineering in the near future [3].

## Nano-materials and their Properties and Applications

There are nanomaterials, for example, nanoparticles, nanotubes, nanowires, and graphene, that have different physical, chemical, and biological characteristics. These materials are used in various fields of science and technology, including electronics, energy, medicine, and environmental clean-up; moreover, nanoparticles can also help in various chemical processes, such as water purification, catalysts, sensing, and medication delivery. Recently, many nanomaterials have been used in the production of nanodevices and biosensors to detect biomarkers, which are biochemicals, metabolites, and other responsible agents produced in a specific type of disease.

### *Nanotubes*

In recent years, interest has emerged in various kinds of nanotubes. The nanotubes contain one dimension between 1 and 100 nanometers and possess entirely different physical, chemical, and biological characteristics in comparison to bulk materials. Although many nanomaterials are already mentioned above, carbon nanotubes (CNTs) are predominantly used for many purposes [5], such as in electronics, energy, medicine, and environmental clean-up. Moreover, CNTs are also applied to target body cells *via* catalysts, sensors, and medication delivery systems. Graphene, another form of carbon, has also been studied for use in electronics and energy storage, but the current paragraph is mainly focused on CNTs and their applications in diagnostic processes. Although CNTs offer attractive possibilities for many applications in their environmental and health cures [5]. Currently, nanotechnology has become so advanced that it can manipulate nanomaterials at the level of individual molecules and atoms. Therefore, several types of nanotubes were constructed and utilized in diagnostics, healthcare, food, electronics, *etc.*

#### ***Structural Features***

Nanotubes are nanosized cylindrical structures with nanoscale diameters and lengths on the micrometer scale. Carbon nanotubes are constructed from carbon atoms and are also known as **carbon nanotubes (CNTs)**. Apart from carbon, nanotubes are also produced from other carbon sources like methane, iron, nickel, cobalt, silicon, quartz, sapphire, and alumina [6].

#### ***Advantages***

A wider range of applications for CNTs are attributed to their physico-chemical properties, such as mechanical strength, electrical conductivity, thermal conductivity, and surface area. However, there are other characteristics that make

# CHAPTER 5

# Current Applications of Nanoparticles in Tuberculosis Therapeutics

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**Abstract:** The global community is deeply concerned with the rapid spread of tuberculosis (TB), a highly contagious and potentially fatal disease. Current treatment regimens are often inadequate, leading to a poor quality of life. Moreover, the emergence of new antibiotics has necessitated the need for more effective therapeutic options. As such, research is being conducted around the world to develop novel strategies to combat TB, with nanotechnology playing a major role in these initiatives. Nanotechnology is an improved tool for existing treatments because of its unique properties and the capacity to enhance therapeutic efficacy. It is being used to target, deliver, and release drugs to infected tissue and cells to increase their absorption and efficacy. Nanoparticles (NPs) have also been shown to deliver anti-TB drugs to infected lungs, which may make the drugs more bioavailable and less harmful to the body as a whole. This book chapter provides a promising outlook on the potential uses of NPs for TB therapeutic development and serves as a guide for future research on infectious diseases.

**Keywords:** Antibiotics, Nanotechnology, Nanoparticles, Infectious diseases, Tuberculosis, Therapeutics.

## INTRODUCTION

Tuberculosis (TB) is one of the oldest and most persistent infectious diseases in human history. Despite decades of efforts to control and eliminate TB, the disease

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remains a major public health threat, especially in low- and middle-income countries. According to the World Health Organisation (WHO), TB is one of the top 10 causes of death worldwide, causing an estimated 1.5 million deaths in 2020 [1]. The emergence of drug-resistant strains of TB has further complicated the fight against the disease. Standard treatments for TB involve a combination of antibiotics taken over a period of several months. However, drug-resistant TB requires longer treatment regimens and often more expensive and less effective drugs. In addition, many people with TB do not take any treatment or are unable to complete the full course of antibiotics, leading to the spread of this infection [2]. The major challenges in TB treatment allow the bacilli of M. tuberculosis to survive and persist within host macrophages that engulf and destroy foreign particles. *M. tuberculosis* also evades the host immune system by forming clusters called granulomas, which prevent the antibiotics from reaching the bacteria [3]. Therefore, there is an urgent need to develop new and effective treatments for TB.

Nanotechnology has emerged as a promising approach for overcoming some of the challenges associated with TB. Nanoparticles are small particles with dimensions typically between 1 and 100 nanometers, and they have unique physical and chemical properties that make them attractive for use in medicine [4]. Researchers are exploring the use of nanoparticles to deliver drugs directly to the site of infection, enhance the immune response to TB, and develop new diagnostic tools for detecting the disease. One of the key advantages of using nanoparticles for TB treatment is their ability to target the bacteria selectively [5]. Antibiotics delivered using nanoparticles can accumulate in the lungs and release the drug gradually, increasing its efficacy while minimizing side effects. Nanoparticles can also be engineered to specifically target the immune cells that are involved in fighting TB, further enhancing the body's response to the infection [6].

Nanoparticles also improve the pharmacokinetics and pharmacodynamics of TB drugs [7]. For example, nanoparticles can increase the solubility, stability, and bioavailability of drugs, leading to enhanced drug efficacy and reduced toxicity. Furthermore, nanoparticles can prolong drug circulation in the body, allowing for sustained drug release and reducing drug administration frequency. By addressing the above potential of nanoparticles, this book chapter will provide an overview of the current state of TB treatment and the challenges and difficulties associated with controlling this disease [8]. It will also discuss the potential of nanoparticles to overcome these challenges and improve TB treatment outcomes.

## Current Scenario and Challenges in Tuberculosis Disease

Tuberculosis is a major public health problem worldwide, with an estimated one-quarter of the world's population infected with *M. tuberculosis*. By 2030, the WHO End TB Strategy aims to reduce the incidence of TB by 80% and the number of TB deaths by 90%. However, the COVID-19 pandemic impacts TB control efforts, disrupting TB diagnosis, treatment, and prevention services [9]. In 2020, there were an estimated 1.4 million fewer TB cases reported than in 2019, and the number of people who started treatment for TB fell by 21% globally. The pandemic has highlighted the fragility of TB control efforts, as well as the need for a more robust and resilient system to address the TB epidemic.

TB diagnosis also presents a challenge, particularly in low-resource settings where diagnostic tools such as chest X-rays and sputum culture are not readily available [5]. The most common diagnostic method is sputum smear microscopy, which has a low sensitivity, particularly in people living with HIV. Newer diagnostic tools, such as the GeneXpert MTB/RIF test, which detects *M. tuberculosis* DNA in sputum samples, have improved sensitivity and specificity compared to smear microscopy. However, these tests are expensive and not widely available in low-resource settings [7]. The lack of access to accurate and timely TB diagnosis results in delayed treatment initiation, which can lead to poor treatment outcomes, including treatment failure and the development of drug-resistant TB.

## Addressing Current Challenges in TB Using Nanoparticles

Nanoparticles have emerged as a promising tool for the management of TB disease. Nanoparticles are tiny particles, typically less than 100 nanometers in size, that have unique physicochemical properties that make them highly attractive for biomedical applications. One of the key advantages of nanoparticles is their ability to penetrate into cells and tissues, which is critical for the effective delivery of drugs to the site of infection [10]. Several different types of nanocarriers have been explored for the management of TB, including liposomes, polymeric nanoparticles, and metallic nanoparticles. Liposomes are lipid-based nanoparticles that can encapsulate drugs and release them at the site of infection.

Polymeric nanoparticles are made from biodegradable polymers and can be designed to release drugs over a prolonged period of time. Metallic nanoparticles, such as silver and gold nanoparticles, have antimicrobial properties and can kill bacteria directly [5]. In addition to drug delivery, nanoparticles can also be used for the diagnosis of TB. Nanoparticle-based biosensors can be designed to detect specific biomarkers of TB infection, such as mycobacterial DNA or proteins, in clinical samples. These biosensors can provide rapid and accurate diagnoses of

# CHAPTER 6

# Nanoparticles and Amalgamation of Stem Cells: A Novel Approach of Treatment in Current Medicine

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**Abstract:** Stem cells (SCs) are fundamental entities in multicellular organisms, possessing remarkable potential for self-renewal and differentiating into various cell types, including neurocytes, osteoblasts, chondrocytes, and hepatocytes. The therapeutic applications of differentiated cells derived from both embryonic and adult SCs hold promise for addressing a spectrum of disorders, ranging from Alzheimer's disease to liver cirrhosis. Despite significant strides in triggering cellular differentiation, the complexities of directing stem cells toward desired cell types remain a formidable challenge. In this context, integrating nanotechnology offers a promising avenue and reproducible therapeutic approach. Recent advancements in the development of inorganic nanoparticles (NPs), metal NPs, and carbon-based NPs, characterized by unique physical and chemical properties, present an opportunity to enhance the differentiation, expansion, and proliferation of stem cells. By leveraging the distinct characteristics of these NPs, researchers can exert control over cellular behaviors and differentiation, thereby augmenting the efficacy of stem cell-based therapeutic approaches. This chapter provides a comprehensive overview of the latest developments in leveraging amalgamated stem cells and NP-based systems for clinical translation. By harnessing the synergistic potential of stem cells and NPs, this innovative approach holds immense promise for revolutionizing treatment modalities in contemporary medicine.

**Keywords:** Alzheimer's disease, Cellular behaviors, Liver cirrhosis, Nanotechnology, Osteoporosis, Osteoarthritis, Stem cells.

## INTRODUCTION

Stem cells are the quiescent primary cells mainly accountable for the development, repair, and replenishment of deteriorated cells and tissues in multi-

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cellular organisms. They have a substantial capacity for self-renewing and competence for differentiation. Upon the availability of external cues, stem cells get differentiated into various types of cells.

Based on the stages of development in animals, stem cells can be classified into embryonic stem cells (ES cells), somatic stem cells, or adult stem cells. A total of three kinds of stem cells can be characterized based on their developmental potential: totipotent stem cells, pluripotent stem cells, multipotent stem cells, and unipotent stem cells [1]. Currently, stem cells such as mesenchymal stem cells or MSCs are extensively being used in therapeutic trials [2]. Even though MSCs can be derived from various tissues like bone marrow, endometrial polyps, umbilical cord (UC), menstrual blood (MB), and adipose tissue (AT), these cells share some common stem cell characteristics that significantly vary in population numbers inside host tissues and their aptitude to proliferate and differentiate *in vivo* counterpart. Owing to the presence of a smaller number of MSCs present in tissues, it is foremost important to expand them *in vitro* before therapeutic intervention [3]. This can be achieved by manipulation of *in vitro* conditions or by using nanoparticles (NPs) to achieve an adequate number of MSCs that facilitate them as excellent candidates for forthcoming implementations in regenerative medicine, clinical sciences, and scientific experiments. MSCs can be differentiated into a range of cell types like neuronal cells, cardiomyocytes, hepatocytes, osteocytes, chondrocytes, adipocytes, and so on, which are representatives of three primary germ layers under *in vivo* and *in vitro* conditions (Fig. **1**).

Stem cell differentiation to corresponding cells and tissues, when engrafted into the body, can repair and replace deteriorated cells or tissues that occur due to disease or injuries. This is why stem cells show greater potential to treat major diseases in humans.

One of the most complicated aspects of deploying stem cell therapies is figuring out how to foster stem cell differentiation *in vivo* whilst witnessing transplanted stem cells or comprehending stem cell differentiation. In this scenario, different nanoparticles (NPs), such as inorganic, organic, and metal NPs, can be used with stem cells for efficient expansion and reliable differentiation to desired cell types. It is documented that various NPs are used as remedial drug therapy for several diseases in the field of biomedicine due to their specific properties, such as controllable size, optical features, magnetic properties, catalytic activities, electrical conductivity, and excellent biocompatible nature [4]. These characteristics of NPs, along with characteristic features of stem cells, create an amalgamated system that is efficiently used to ameliorate specific conditions associated with neuronal, bone-related, and liver diseases.

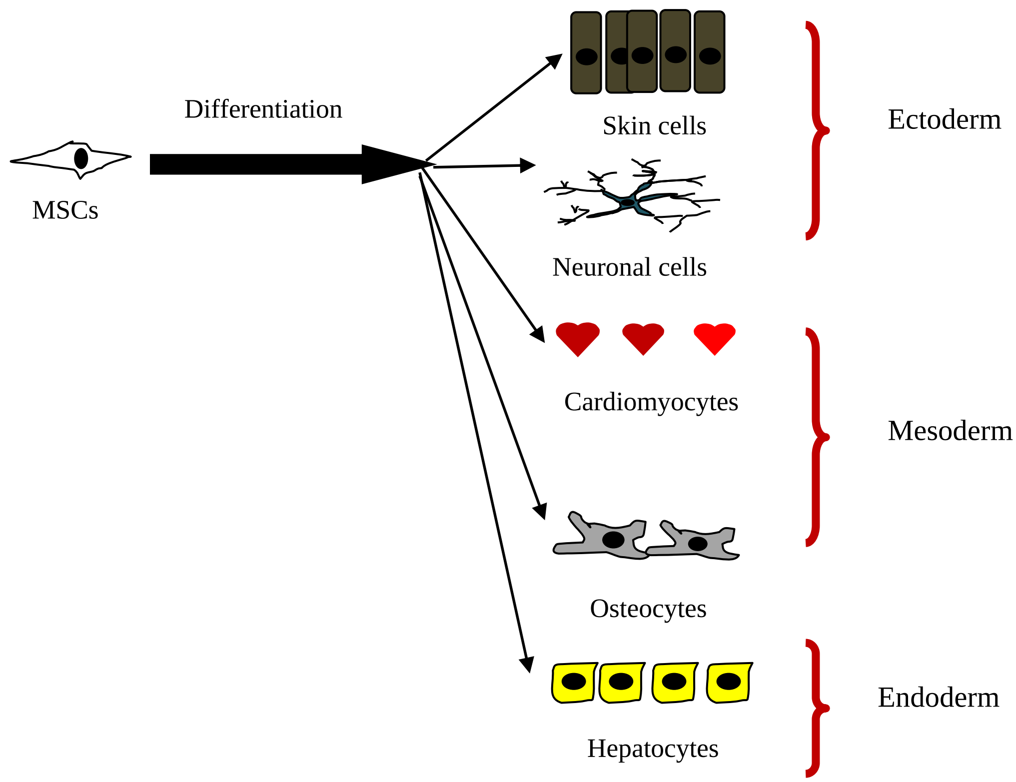


**Fig. (1).** Differentiation of MSCs into various cell types.

## NPs

NPs act as easy transport vehicles that deliver several bioactive and targeted molecules to their desired location. It facilitates the production of most drugs that can be used in multiple regenerative medicines. These are the most supportive molecules that participate in the trapping of small particles that act as active reagents used in tissue engineering [5]. NPs have a significant surface-to-volume ratio since they are regarded as nanomaterials with at least one exterior dimension ranging from 1 nm to 100 nm [6]. Depending on the method of preparation, there are three types of nano-structures available: NPs, nanospheres (NSs), and nanocapsules (NCs). NSs are organized milieu in which the drug is uniformly and physically distributed, whereas NCs are special polymer membrane systems that enclose the drug within a cavity. The NPs exhibit distinct biological, physical, and chemical properties at the nanoscale level, contrary to their size at greater scales. This impact is brought about by a surface area to volume ratio that is significantly higher than average, as well as greater chemical reactivity or stability, improved mechanical strength, *etc.* A wide range of attributes, such as being stronger,

**CHAPTER 7**

# The Therapeutic Potential of Nanoparticles in Healthcare

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**Abstract:** Healthcare has undergone an important change as a result of nanotechnology, which promises historically unseen possibilities for therapeutic, preventative, and diagnostic nanointerventions An overview of the therapeutic potential of nanoparticles (NPs) in healthcare is given in this abstract, with particular attention on how they may be used in targeted treatment, imaging, and drug delivery. Because of their special physicochemical characteristics, nanoparticles are a great option to get beyond conventional medication delivery restrictions. Their control over drug release kinetics is made possible by their customizable size, surface chemistry, and biocompatibility, which maximizes therapeutic efficacy and reduces adverse effects. Additionally, because NPs may cross biological barriers like the blood-brain barrier, therapeutic medicines can be delivered to certain tissues or cells with precision. By enhancing solubility, preventing drug degradation, and promoting prolonged release, these nanocarriers maximize therapeutic effects. Additionally essential to medical imaging, nanoparticles offer improved contrast for diagnostic imaging. This improves monitoring, early identification, and individualized treatment plans. Targeted therapy has also been transformed by the development of nanotherapeutics, which enable controlled release and site-specific drug delivery in diseased tissues. By using ligands or antibodies on NP surfaces, active targeting technologies allow for the selective identification and binding to certain cell receptors, which enhances medication absorption by sick cells while reducing off-target effects. Notwithstanding these encouraging developments, issues with scalability, toxicity, and biocompatibility still need to be resolved before nanotherapeutics may be widely and safely used in clinical settings. This abstract underscores the transformative potential of nanoparticles in revo-

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lutionizing healthcare, paving the way for personalized and more effective therapeutic interventions across a spectrum of diseases.

**Keywords:** Cancer therapy, Drug delivery, Liposome, Magnetic nanoparticles, Vaccine.

## INTRODUCTION

Nanoparticles, materials with dimensions ranging from 1 to 100 nanometers, have emerged as promising entities in the realm of therapeutic applications due to their unique physical and chemical properties. The field of nanotechnology has provided a platform for the design and engineering of nanoparticles with tailored characteristics, enabling targeted and controlled delivery of therapeutic agents [1]. Nanoparticles in therapeutic strategies represent a paradigm shift in drug delivery and treatment modalities. These minuscule structures offer several advantages, including increased surface area, tunable reactivity, and the ability to navigate biological barriers that may impede traditional drug formulations. In the context of therapeutic applications, nanoparticles have demonstrated remarkable potential in drug delivery, diagnostics, imaging, and various other medical interventions [2]. One of the key areas where nanoparticles have shown considerable promise is in drug delivery systems. The ability to encapsulate drugs within nanoparticles facilitates their transport to specific target sites, minimizing systemic side effects and enhancing therapeutic efficacy. Additionally, the unique physicochemical properties of nanoparticles can be exploited to overcome biological barriers, such as the blood-brain barrier, enabling the delivery of therapeutic agents to previously inaccessible areas [3]. In diagnostic imaging, nanoparticles serve as versatile contrast agents, enhancing the visibility of tissues and improving the accuracy of medical imaging techniques. The precise control over the composition and surface characteristics of nanoparticles allows for their customization to meet the specific demands of various imaging modalities, including magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound [3]. Despite the tremendous potential of nanoparticles in therapeutic applications, challenges such as potential toxicity, biocompatibility, and scalability must be addressed [4]. The multifaceted landscape of nanoparticles in therapeutic applications sets the stage for a comprehensive exploration of their role in drug delivery, imaging, and other innovative medical interventions. As research in nanotechnology advances, the potential for transformative breakthroughs in healthcare continues to grow, marking an exciting era in the development of novel therapeutic strategies.

Nanoparticles have gained significant attention in therapeutic applications due to their unique properties at the nanoscale. These particles, typically ranging from 1 to 100 nanometers in size, offer distinct advantages in drug delivery, imaging, and diagnostics. Here are some ways in which nanoparticles are used in therapeutic applications (Fig. **1**):

## DRUG DELIVERY

The role of nanoparticles in targeted drug delivery is transformative, offering a paradigm shift in the way we approach the treatment of various diseases. The precision, enhanced pharmacokinetics, and ability to overcome biological barriers make nanoparticles a promising tool for delivering therapeutic agents with unprecedented accuracy and efficacy [5]. Nanoparticles can be designed to carry therapeutic agents, such as drugs or genes, directly to the target site in the body. This minimizes side effects and enhances the therapeutic effect. Targeted drug delivery represents a cornerstone in the application of nanoparticles within the realm of nanomedicine. This high specificity ensures that therapeutic agents are delivered precisely to the intended target, minimizing collateral damage to healthy cells [4, 5]. The size and surface properties of nanoparticles can be tailored to optimize their pharmacokinetics. This allows for prolonged circulation times in the bloodstream, avoiding rapid clearance and improving the overall bioavailability of the drug. As a result, the therapeutic payload can reach the target site in sufficient concentrations, enhancing treatment outcomes. Additionally, certain nanoparticles can traverse cellular barriers, such as the blood-brain barrier, enabling the delivery of drugs to the central nervous system [6]. It can be designed to facilitate controlled drug release, providing a sustained and prolonged therapeutic effect. This is particularly valuable in chronic conditions where maintaining a consistent drug concentration is crucial for optimal treatment. This opens avenues for personalized medicine, where treatment regimens can be tailored to the specific needs of each patient, considering factors such as genetic variations and disease heterogeneity. By delivering drugs directly to the target site, nanoparticles help minimize systemic exposure and, consequently, reduce side effects associated with off-target effects. This targeted approach not only enhances the safety profile of therapeutic agents but also improves the overall tolerability of treatments. As research on nanomedicine advances, the potential for developing innovative and patient-centric drug delivery systems continues to grow, ushering in a new era in healthcare [7].

## CANCER THERAPY

Cancer stands as a leading cause of both mortality and morbidity, characterized by a complex pathophysiology. Conventional cancer treatments encompass chemotherapy, radiation therapy, targeted therapy, and immunotherapy; however, challenges like lack of specificity, cytotoxicity, and multi-drug resistance present

# CHAPTER 8

# Recent Advancement in the Epigenetic Mediated Nanotechnology Approach: Potential Implication in Cancer Therapy

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**Abstract:** Cancer is a major cause of morbidity and mortality and exhibits a potential health burden worldwide. Despite significant advancements in chemotherapy, radiotherapy, surgery, and immunotherapy, early-stage diagnosis, lack of a specific biomarker, and recurrence of the disease urgently necessitate an alternative diagnostic approach. Multiple lines of evidence show that epigenetic factors, such as DNA methylation and histone modifications, play a crucial role in modulating the onset and progression of cancer phenotypes. Furthermore, epigenetic drugs in clinical settings are highly efficient and ideal with regard to patient response and reproducibility. However, owing to their toxicity, low solubility, poor bioavailability, and low stability, epigenetic drugs can lead to off-target effects and might fail to induce a long-term response. Recently, it has been observed that the integration of epigenetic drugs with nanoscale delivery systems offers a novel and promising approach not only for the targeted delivery of epigenetic drugs to the tumor site but also enhances the stability and permeability with improved efficacy and reduced systemic toxicity. Leveraging this concept, the current chapter aims to elucidate the recent advancements and futuristic approach of nano-epigenetic drug conjugates and their potential implications in cancer therapy.

**Keywords:** Cancer, DNA methylation, Histone modification, Nano-epigenetic drug, Nanotechnology.

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## INTRODUCTION

Cancer has become the second largest cause of death, with cardiovascular disease being the leading cause of death globally [1]. The most common cancers are breast, lung, colon, rectum, and prostate cancers. Widespread metastasis is the primary cause of cancer-related death. Metastasis occurs when cancer cells grow rapidly, invade adjoining parts of the body, and spread to other organs. Cancer mortality can be reduced through early detection and treatment. Commonly, treatment of cancers is limited to traditional chemotherapy, radiation therapy, and surgery [2]. The etiology of cancer can be quite complicated as it involves both environmental and hereditary influences.

The application of various nanotechnologies in cancer studies has become a rising field and approach aimed at providing early diagnosis, prediction, different therapeutic treatments, and drug design and delivery. Despite the significant advancements in chemotherapy, radiotherapy, surgery, immunotherapy, and early-stage diagnosis, the lack of a specific biomarker and recurrence of the disease urgently necessitate an alternative diagnostic approach. One of the main applications of nanotechnology in cancer research is the development of diagnostic tools. In this context, alternative diagnostic approaches are urgently needed [3, 4].

One of the main applications of nanotechnology in cancer research is the development of nanomaterials for drug delivery. Nanoparticles can be designed to deliver drugs directly to the cancer cells, thereby reducing the side effects of chemotherapy. Nanoparticles can be used to deliver these drugs directly to cancer cells, increasing their efficacy and reducing their toxicity. Nanoparticles can also be used to study epigenetic modifications in cancer cells. One of the challenges in studying epigenetics is that it is difficult to isolate and analyze the epigenetic marks on DNA. Nanoparticles can be designed to bind specifically to certain epigenetic marks, allowing researchers to isolate and study them. For example, nanoparticles have been designed to bind to histone modification, allowing researchers to study the role of histone modification in cancer development.

Besides all of these applications, different cancer drugs and traditional cancer therapies in the clinical setting are only highly efficient and ideal as far as the patient response and reproducibility are concerned. However, owing to the toxicity, low solubility, poor bioavailability, and low stability associated with certain cancer drugs, it can lead to off-target effects and failure to induce long-term responses. Recently, it has been observed that the integration of epigenetic drugs with a nanoscale delivery system offers a novel and promising approach not only in the delivery of the drugs to the tumor site but also for enhancing stability and permeability with minimum side effects [5]. To address these limitations, the integration of epigenetic drugs with nanoscale delivery systems offers a novel and promising approach to cancer therapy. Leveraging this concept, the current chapter aims to provide an overview of recent advances and future perspectives on nano-epigenetic drug conjugates and their potential impact on cancer therapy.

## EPIGENETICS PLAYS A MAJOR ROLE IN CANCER

Conrad Hall Waddington first coined the term epigenetics in the early 1940s and referred to it as a molecular mechanism that influences changes in gene expression but does not involve changes in its genetic code. Epigenetics is also understood as the study of heritable changes in gene expression that arise without any changes in DNA sequence [6]. Epigenetic modifications can alter the manner in which genes are expressed, potentially leading to the development of cancer. Multiple lines of evidence show that epigenetic factors, such as DNA methylation and histone modifications, play a crucial role in modulating the onset and progression of cancer phenotype Fig. (**1**) [7]. Non-coding RNAs, such as small RNAs, also play an important role in the regulation of gene expression by controlling mRNA translation. Regions that target miRNAs are often associated with carcinogenesis. Post-translation modifications of histone, such as methylation, are crucial regulators of chromatin structure and gene expression and, therefore have been a major target of epigenetic therapies [8].

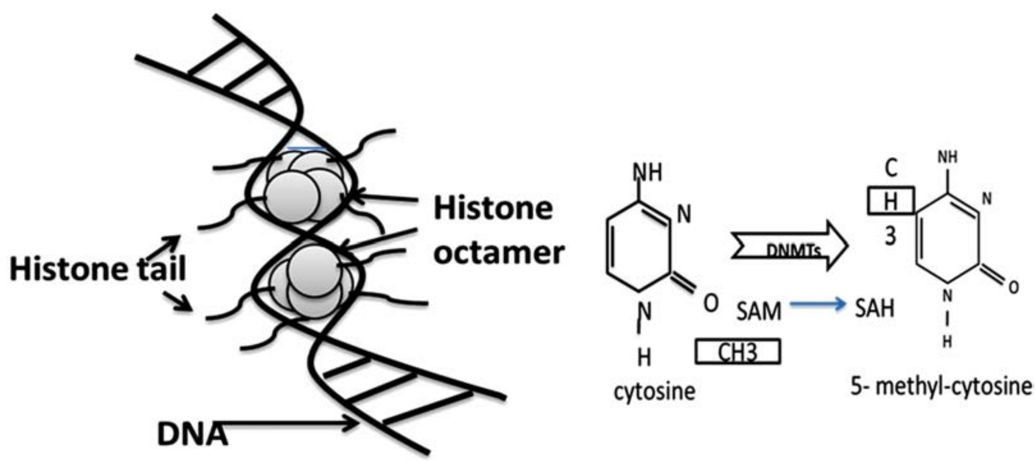


**Fig. (1).** Histone modification.

Epigenetic drugs are a promising class of new cancer therapeutics that target epigenetic modifications in cancer cells. These drugs work by modifying epigenetic marks on DNA, altering the expression of genes, and potentially

# CHAPTER 9

# Artificial Intelligence and Nanotechnology-Integrated Recent Applications in Early Lung Cancer Detection and Therapy

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**Abstract:** Globally, lung cancer is a leading cause of mortality resulting from mutating genes and altered pathologies. Early-stage detection of such lethal disease is very critical, and subsequent nanomaterial-based personalized drug delivery systems can help reduce death rates when metastasized tumors have not spread to other regions of the body. Artificial intelligence and nanotechnology, collectively known as nanoinformatics, have advanced challenging scopes in nanotherapeutics. Artificial intelligence-based computer-aided diagnosis systems have huge potential in performing early theranostics by integrating machine learning and deep learning techniques in lung cancer detection. These models have a high degree of accuracy, specificity, and sensitivity due to artificial intelligence-based image processing and segmentation techniques. The emergence of widespread applications of nanotechnology in the design of site-specific novel drug delivery systems is crucial in lung cancer therapy as they can target cancerous cells. Optimizing nanomaterials' properties have proven to be beneficial in therapy in accordance with the interaction of drugs with biological fluid and the immune system. Embedded nanocarriers in carbon nanotubes, polymeric micelles, and liposomes possess great pharmacokinetic and pharmacodynamic potential in the management of the healthcare of lung cancer patients.

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**Keywords:** Artificial intelligence, Lung cancer, Nanotechnology, Nanoinformatics, Nanotherapeutics.

## INTRODUCTION

Cancer is a set of diseases that are distinguished from one another by the abnormal and uncontrolled proliferation of cells originating from a variety of sources, and it can affect a number of organs throughout the body. Cancer is the primary reason for mortality in many parts of the world [1]. Malignancy, the name of cancer, is the unchecked or abnormal proliferation of cells that weakens our immune system. Human cells divide by a process known as mitosis *via* cell growth and multiplication, followed by a programmed death, which replaces the old ones with the newer ones. When this orderly apoptotic process fails, there is unceasing growth and multiplication of cells, which ultimately results in the development of a lump or tumor, which can either develop into cancer or sometimes remains as a noncancerous mass (benign tumor). Cancer is basically a disorder that develops due to the genetic mutation in the cells upon their exposure to various noxious stimuli, viz. chemicals, fumes and smoke, radiations, viruses, *etc.* It is observed that about 200 different types of cancer are present. It can be classified according to the organ in the body in which it first appears (for example, cancer of the brain, cancer of the lungs, cancer of the cervix, *etc.*). Another way to categorize cancer is by the type of cell in which it first manifests. There are only a few main categories of cancer, and each is characterized by its cellular origin. They are as follows [2]:

### Carcinoma

A form of cancer known as epithelial carcinoma that starts in the cells that line or cover internal organs, such as the skin or tissue of the esophagus, kidney, pancreas, prostate gland, head, neck, *etc.* Some of the subtypes of cancer comprise adenocarcinoma, basal cell carcinoma, transitional cell carcinoma, and squamous cell carcinoma.

### *Sarcoma*

It starts in mesenchymal connective tissues such as bones, cartilage, blood vessels, muscle, adipose tissues, *etc.*

### Leukaemia

This particular form of cancer attacks the white blood cells in the body. It develops in the tissues responsible for producing blood cells, such as bone marrow.

## Lymphoma and Myeloma

Myeloma, on the other hand, is a type of cancer that affects the plasma cells, whereas lymphoma affects the lymphatic system.

Lung cancer is the only form of the many types of prevalent malignancies estimated to be responsible for nearly 1.80 million deaths worldwide in 2020-21. Lung cancer is also the second most common form of malignancy, accounting for 20% of all cancer-related deaths.

## Lung Carcinoma

Among the several kinds of lung cancer, the most frequent are non-small cell lung cancer (NSCLC) and small cell lung cancer (SCLC). Of the total number of lung cancer cases, NSCLC accounts for 85 percent, while SCLC makes up the remaining 15 percent. NSCLC can be further divided into three different subtypes: Adenocarcinoma, squamous cell carcinoma, and giant cell carcinoma. The most common subtype is adenocarcinoma, which typically develops in the lungs' outer layers [3]. The middle of the lungs is the most common location for the development of squamous cell carcinoma, which is commonly related to smoking. The less prevalent form of lung cancer, known as large cell carcinoma, can arise in any area of the lungs. On the other hand, the SCLC can be further subdivided into three subtypes, each of which has a distinctive therapeutic profile and prognosis. These subtypes are the small cell carcinoma, the mixed small cell and large cell carcinoma, and the squamous cell carcinoma. Regardless of the subtype, lung cancer typically starts as abnormal cells that grow out of control, eventually forming a tumor [4]. Early lung cancer diagnosis enables the development of effective treatment plans. However, most cases of lung cancer are detected at a more advanced level. Detecting lung cancer nodules manually from the image modalities with the naked eye is a laborious task [5]. The requirement for a second opinion as a result of a scarcity of healthcare experts has a substantial influence on the procedure [6]. Thus, it appears that early identification of lung disorders is crucial for avoiding lung cancer. Artificial intelligence, which includes deep learning (DL) and machine learning (ML) techniques, which are incorporated into computer-aided diagnosis systems, plays a crucial role in the early diagnosis of lung cancer [7]. Conventional healthcare management has limitations, but predictive approaches such as deep learning (DL) algorithms can assist in circumventing them. The adoption of DL-based detection might minimize invasive procedures, hence improving the efficacy and sustainability of present healthcare practices [8]. In addition, radiomics is the process of extracting data that can be obtained from medical imaging. This data is then used in oncology to enhance diagnostic capabilities and clinical decision-making to

# CHAPTER 10

# Heavy Metal Adsorption by Plant Phenolic Polymer: Lignin Nanoparticles

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**Abstract:** Due to the extreme toxicity of heavy metal ions, water pollution caused by them is currently a major concern. The search for novel, economically viable adsorbents derived from biomass has been intensified recently. Heavy metals are causing a growing number of pollution incidents, leading to significant harm to the health of human beings and also affecting the aquatic environment. Therefore, there is a need for effective and efficient methods for removing high atomic weight metal ions. Lignin is a complex biopolymer that has tremendous scope for usage as a material for the development and production of biodegradable products. Herein, novel hybrid nanoparticles can be prepared. Owing to its distinct physicochemical properties, crosslinked phenol structure, and availability, lignin can be used to possibly generate broad ranges of sorbents, especially those that adsorb heavy metal ions. Thus, the objective of this chapter is to explore the different categories of modifications in the process of lignin's transformation into sophisticated adsorbents for heavy metal ions. Additionally, lignin-derived adsorbents are able to offer significant ecological advantages because of their biocompatibility, stability, and abundance in the plant world. The development of novel lignin-based adsorbents with improved heavy metal ion adsorbent performance may be facilitated by the information in this chapter.

**Keywords:** Adsorption, Biomass, Composite, Heavy metal, Lignin nanoparticle.

## INTRODUCTION

A class of metals identified as heavy metals and metalloids includes those with atomic numbers greater than 20 and densities greater than 5000 kg/m$^3$. Even in trace amounts, they are harmful to humans despite the fact that some of the heavy

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metals and metalloids are naturally occurring elements with biological functions [1]. Some examples are cadmium, iron, arsenic, lead, nickel, mercury, chromium, zinc, silver, *etc.* In an environmental context, they can be defined as metal (and metalloid) species that are typically bio-accumulative, cannot easily be decomposed by natural factors, and have the ability to cause cancer [2].

Concern about heavy metals' potential for harming humans and other life forms began with the hazardous activity of these substances on organisms that had been observed as early as the late 19th century [2]. Following that, techniques for accurately determining the accumulation of heavy metals and tracking their distribution, occurrence, and future have been developed. Water pollution and environmental degradation pose the biggest threats to the biodiversity of sources of drinking, agricultural, and industrial water worldwide. One significant class of harmful substances found in water sources and often produced by human industrial activity on earth are heavy metals. Elements like As, Cd, Pb, and Hg are unnecessary for plants and animals, and at any amount of exposure, they are hazardous to all biological processes. Because of this consequence, even in extremely low quantities, they may be harmful to species. Heavy metal toxicity is correlated with their oxidation states. For instance, Cr(III) appears to be less harmful than Cr(VI), which is extremely toxic [3].

The bioavailability of heavy metals is a crucial factor in toxicity assessments. Higher bioavailable metal fractions provide more danger to animals and plants. The total concentration of a particular metal that enters cells, rather than its total amount in the environment, determines how harmful it is. Various heavy metal cleaning methods, including physical, chemical, electrical, and biological methods, have been proposed [4]. It is frequently difficult to decide on the best decontamination technique because of this. Sometimes more than one strategy was required for effective results. Chemical precipitation, ion exchange, coagulation, electrochemical methods, and adsorption are among the most applied technologies [5].

Bioaccumulation is a significant feature of their pollution since harmful heavy metals build up in human tissues through the food chain. According to the duration and intensity of exposure, heavy metal exposure in humans can result in a variety of disorders [6, 7]. Short-term exposure to heavy metals can harm the kidney, liver, and lungs, among other organs, as well as the gastrointestinal, cardiovascular, and central neurological systems. On the other hand, exposure for a long time has been linked to a number of degenerative conditions and may raise the chance of developing certain cancers. Hexavalent chromium, for example, can cause apoptosis of human lung fibroblasts, making them hazardous. Several heavy metals, including Pd, As, Cd, and Hg, can also cause cancer [8 - 10]. The majority of industrial waste include numerous high-risk metals, and the present equipment and technology for treating pollutants are partially efficient [11]. It is necessary to build enhanced systems of purification to treat heavy metal ions in industrial regions.

Furthermore, a number of techniques have been accessed to highlight the shortcomings and potential to eliminate heavy metals, and their combination has been identified, which provides a potential way for developing effective hybrid technologies. Since it is efficient, inexpensive, and friendly to the environment, adsorption is frequently used in the treatment of wastewater (Table **1**). It is important to find the optimum adsorbent, one that has strong adsorptive performance and minimal environmental effect and that can be simply separated from wastewater.

**Table 1. The benefits and drawbacks of the adsorption method.**

| Benefits | Drawbacks |
| --- | --- |
| Flexibility, ease of use, cheap cost, and excellent effectiveness against heavy metal contaminants | It removes heavy metals from water through hydroxide precipitation by forming metal hydroxides. |
| It produces excellent wastewater and effluent treatment. | The discharge of precipitated hydroxide into the environment is a major drawback. |
| Adsorbents can be regenerated and utilized again using appropriate desorption techniques. | During adsorption, it has a bit of a reversible property. |
| Low concentrations of high atomic mass metals are removed from effluent using adsorption. | Adsorption might not remove heavy metals efficiently from the inorganic wastes hence precipitation using chemicals is used alternatively. |

## LIGNIN POTENTIAL AS HEAVY METAL ABSORBER

Carbonaceous materials have extensive utility as adsorbents for the water treatment industry because of their excellent chemical stability and high specific surface area [12]. Activated carbons, for instance, are made using fossil fuels like coal and oil, as well as nanoscale carbons like carbon nanotubes and graphene. However, producing and renewing activated carbon is an expensive and energy-intensive process [13]. To replace the expensive activated carbons, a renewable organic biomass material that is inexpensive, ecologically friendly, and contains a significant proportion of carbon could potentially be used [14]. The majority of cellulose, including hemicellulose and lignin, consisting of carbonyl, hydroxyl, and carboxyl groups on their surfaces, are found in biosorbents obtained from plant residues. Surface functional groups have a major role in the potential of biosorbents made from plant wastes [15]. These include a broad variety of adsorbates, such as inorganic ions of heavy metal. A naturally occurring

# CHAPTER 11

# Bioremediation using Nanomaterials: A Prospective Approach for Environmental Decontamination

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**Abstract:** With a focus on environmentally friendly, sustainable technology, new technologies such as the combined process of nanotechnology and bioremediation are urgently needed to accelerate the cost-effective remediation process to alleviate toxic contaminants compared to conventional remediation methods. Numerous studies have shown that nanoparticles possess special qualities, including improved catalysis, adsorption, and increased reactivity. This chapter explores the potential of nanomaterials in bioremediation for environmental decontamination. Bioremediation is a sustainable and eco-friendly approach to remove pollutants from contaminated soil and water. The application of nanotechnology in bioremediation has gained attention due to the unique properties of nanomaterials, such as high surface area, reactivity, and selectivity. The content discusses recent developments in using various nanomaterials, including carbon-based, metal-based, and hybrid nanomaterials, to remove organic and inorganic pollutants from the environment. Also, this highlights the advantages and limitations of using nanomaterials in bioremediation, including their potential toxicity and long-term effects on the environment. Furthermore, we provide insights into the prospects of using nanomaterials in bioremediation and the challenges that need to be addressed for the effective and safe use of nanomaterials in environmental decontamination.

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**Keywords:** Bioremediation, Environmental decontamination, Nanomaterials, Nanotechnology, Sustainable technology.

## INTRODUCTION

The excessive growth in urbanization and industrial development since the late 19th and early 20th centuries has made it possible for us to achieve new heights in technological and economic progress. This has, in turn, made our quality of life much more advanced. Still, at the same time, the uncontrolled use of industrial techniques, excessive extraction of non-renewable resources, and disposal of toxic waste materials into the environment without proper monitoring have had detrimental effects on our health. It is increasing with every new advancement that humanity makes [1]. The increasing contamination issues are giving rise to numerous complicated infectious diseases, among which respiratory infections and contact dermatitis are the leading ones [2 - 5].

The industrial revolution surrounding the chemical technology industry and its derivatives has given rise to increased levels of trace metals in our surrounding environment [2, 6, 7]. This, in turn, causes the accumulation of metal ions as sediment in the soil and water bodies. Sediment is the primary source of heavy metals in the environment. They can be formed in many ways- 1) Atmospheric deposition of heavy metals like cadmium (Cd), lead (Pb), and mercury (Hg) causes build-up in soil. 2) Wastewater discharge containing zinc (Zn), nickel (Ni), and copper (Cu) can cause hazardous effects on living organisms. 3) Rain leaching refers to a process where heavy metals such as chromium (Cr) and arsenic (As) are transferred to a liquid medium (such as water) from a stable matrix due to the influence of acid rain [8, 9]. Apart from these methods, there are cases where the chemical, as well as the physical characteristics of the water containing the HMs (heavy metals), may change, and this causes the HMs to return from the sediment to the topmost layer of the water in response to the changes occurring in the water. This is known as secondary pollution [10]. The toxicological effects of HMs, the risks of bioaccumulation, and other environmental concerns are why heavy metal contamination has become a severe issue that needs to be solved [11 - 13].

Apart from HMs, various toxic contaminants, like phenol and its derivatives, are found in large quantities in our surrounding environment. The most notable are the halogenated phenols classified as anthropogenic pollutants, meaning that humans have contributed to creating this pollutant [14]. It is also mutagenic and carcinogenic in nature [15]. Various effluent plants and wastewater from different industries, domestic households, chemical spills, and agricultural lands are causing severe contamination of the surrounding water bodies [16]. There are also harmful solid waste materials composed of various dangerous and toxic components. These can be organic or inorganic in nature and are mostly non-biodegradable. These have long-term detrimental effects on soil vitality and fertility and the health of humans and other animals [17, 18].

The pesticides, insecticides, and fertilizer industries produce a considerable amount of solid and liquid waste. The excessive use of pesticides and fertilizers is making the surrounding soil and water poisonous. These toxic and harmful chemicals may enter our food chain through various methods like a) Bioaccumulation- which is the net accumulation of contaminates in an organism [19] and b) Biomagnification- which is the chemical transfer of a toxin from a lower trophic level to higher trophic levels within a food chain resulting in high concentrations of the toxin in question in the apex predators [20]. Given these harmful and adverse conditions, much more research is needed to develop cost-effective decontamination processes. In recent years, new technologies for effective contamination removal have been developed. Among these, bioremediation has gained much interest due to its green and sustainable techniques for treating pollutants [21]. It is also very flexible and can be implemented on a large scale for better waste management [22]. This bio-based approach has profound effects in protecting the environment, and thus, it is considered an ‘environmentally appropriate’ method. Some examples of bioremediation are- a) Biostimulation- where the growth of the indigenous microorganisms is stimulated, and b) Bioaugmentation- where non-native oil-degrading bacteria are inoculated for the acceleration of the detoxification process in a polluted site with minimal impact on the ecological system [23, 24].

Even though bioremediation is an excellent, practical, and flexible method for dealing with different pollutants, it has a few drawbacks - a) It is often time-consuming as it involves bio-based techniques. b) It performs poorly when there is a high concentration of pollutants, and there is a chance of toxicity in the organism being used for the treatment. c) when dealing with xenobiotics, the treatment efficiencies are drastically low, along with prolonged recovery time [25]. For these reasons, the appropriate selection of the best remediation method is necessary. However, applying only a single technique is not recommended for contamination remediation.

In recent years, the emergence of bio-mimetic nanotechnology has become an innovative strategy to take the bioremediation process forward beyond its current capabilities [26]. This has caused a sudden influx of researchers in this unexplored field. Nanomaterials (NMs) can be defined as materials with the particle’s size being 100nn or less in at least one dimension. The new and innovative nano-bioremediation process consists of nanoparticles (NPs) with two or more

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