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EMERGING TRENDS IN ADVANCED FUNCTIONAL NANOMATERIALS AND NANOPARTICLES BASED ON BIOMEDICAL ASPECTS

Ramu Sharma
Research Scholar Dept. of Physics, Lalit Narayan Mithila University, Darbhanga. Bihar
Md Naushad Alam
HOD Dept. of Physics, Lalit Narayan Mithila University, Darbhanga. Bihar
Arun Kumar Singh
Professor Dept. of Physics, Lalit Narayan Mithila University, Darbhanga. Bihar
Deepak Kumar
Assistant Professor, Dept. of Physics, Lalit Narayan Mithila University, Darbhanga, Bihar
Pritam Kumar
Assistant Professor Dept. of Physics, G.D College, Begusarai

Abstract

Nanotechnology has enabled significant progress in biomedical research. Ranging from diagnostics to therapeutics, nanomaterials have been widely exploited in the fields of biomedicine and bioengineering. Nanoparticles (NPs) offer great promise for biomedical, environmental, and clinical applications due to their several unique properties as compared to their bulk counterparts. The past few decades have witnessed the development of several nanomaterials for bringing out the best results in the field of medical diagnosis. However, despite possessing extremely unique material properties, many of them lack surface heterogenic reactivity, which is a crucial factor for the specific binding of biomarkers on the nanomaterial surface. Nanotechnology has broad implications across multiple industries, including electronics, medicine, materials science, and energy, and it holds great potential for revolutionizing technology and addressing some of the world's most pressing challenges. This field has opened up new possibilities for creating innovative materials, devices, and systems with unprecedented precision and logicality. Understanding their properties promotes research in the medical and biological sciences and improves their applicability in the health management sector. The significant role medical diagnostics play in everyday life (for example, the new generation of glucose testing for diabetics) is a direct result of the understanding of biomolecular recognition events and the ability to manipulate them in useful, easy-to-use devices.

Keywords: Nanoparticles, Surface modification, medical diagnosis, Biomarkers,

1. Introduction

Nanotechnology products have become increasingly useful in biomedicine and have led to the advent of a hybrid science named nanobiotechnology. Nanomaterials have noteworthy applications in nanobiotechnology, particularly in diagnosis, drug delivery systems, prostheses, and implants. Nanoscale materials integrate well into biomedical devices because most biological systems are also nanosized. The materials commonly used to develop these

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nanotechnology products are inorganic and metal nanoparticles, carbon nanotubes, liposomes, and metallic surfaces. By using chemical or physical methods and taking advantage of specific biological reactions, such as the antibody-antigen interaction, receptor-ligand interaction, and DNA–DNA hybridization, it is possible to conjugate biospecific molecules with nanoparticles. As the human population ages and the future expands, tissue wounds and pathophysiology will keep on expanding, imposing a real physical and money-related strain on the overall social insurance frameworks. To this end, it is foreseen that biomaterial NPs will offer the best way to deal with regenerative medicine that will assume an urgent role in the regeneration of damaged body parts. It is believed that the field of bioactive nanomaterials will keep on exponentially developing in the future. Nanomaterials that can be classified as bioactive nanomaterials are divided into two categories according to their origin, either natural or synthetic nanomaterials; the general applications of nanomaterials in the medical field are categorized in figure 1.

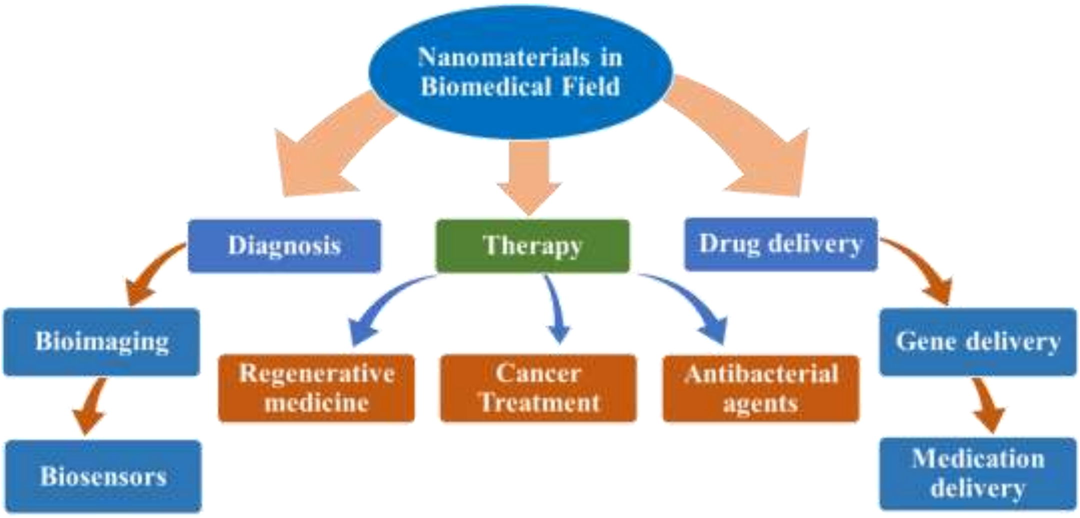

Figure 1. Some Biomedical Applications of Nanomaterials.

Several applications of biomaterials in biomedical applications have been already approved, such as heart valves, plastic surgery, joint substitutions, drug delivery devices, and other restorative applications [1-6]. The entry of new items in these fields, for example, plastic medical procedures, nervous system regeneration, and wound treatment, is relied upon to enhance the development of this market. The market of cardiovascular biomaterials overwhelms other biomaterial markets because of the high incidence rates of cardiovascular diseases, and the market of orthopedic biomaterials is the second biggest market in the biomaterials field. There is a mismatch between the rate of innovation of nanomaterials and their application in the biomedical field. While most individuals from the exploiter network can get a handle on the significance of nanotechnology and can expertly dispatch and deal with a reasonable item on the market, they are restricted in their applied comprehension of this logical order and the unpredictable internal activities behind the item's usefulness.

2. Relation between Biology and Nanomaterials

As we know that living organisms are made up of smaller sub-units called cells. However, the cell organelles present inside cells are even smaller, which are quite comparable

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to man-made nanoparticles (NPs). Hence, these NPs can act as small probes that allow us to spy on cellular machinery without any obstruction.

The medical applications of nanostructured biomaterials are in the form of polypeptides, proteins, nucleic acid, DNA-based self-assemblies, biopolymers, cells, glycans, etc., which are involved in studying the bio-compatibility and interaction between nanoscale biomaterials like cells, tissues, and organs, as well as their application in a variety of medical and health sciences, including nanocarriers for drug, gene and vaccine delivery, Orthopaedics, cardiovascular, dentistry, etc. This scientific development is quite a promising approach. These aspects of nanotechnology are explored via the use of nanoscale biochips that will transmit information and monitor the biological changes in humans. Major advances are emerging in the form of DNA chips, carbohydrate chips, protein chips, and MEMS/NEMS, where a single biochip processes more than a million features with supersensitive detection, diagnostics, and analytical monitoring abilities. A few basic nanomaterials have adsorption properties for different medicines, such as ibuprofen, naproxen, and paclitaxel. Silica nanoparticles have been widely explored in biomedical applications, mainly related to drug delivery and cancer treatment. These nanoparticles have excellent properties, high biocompatibility, chemical and thermal stability, and ease of functionalization. Moreover, silica is used to coat magnetic nanoparticles protecting against acid leaching and aggregation as well as increasing cytocompatibility. Silica nanoparticles present not only high biocompatibility but also exhibit high surface area and reactive sites that enable the conjugation with biocide compounds [7-8]. Nanotechnology is potent enough to play a significant role in a variety of biomedical and bioengineering applications. The past few years have witnessed a tremendous elevation in the development of numerous strategies based on nanotechnology, thus surmounting the shortfalls of traditional targeted therapies. NPs are utilized for the delivery of drugs in the form of nanocarriers and nanomedicine, for disease diagnosis, pest management, environmental health monitoring, improving crop production, detecting vitamins and biomolecules therapeutic and diagnostic advances, sensing food-borne pathogens, as volatile organic compound sensing systems and developing different electro-chemical sensors, biosensors, and biosensing-related gadgets. The development of optical plasmonic sensors employing various nanomaterials for different biomedical and biosensing applications has gained momentum in the past few years owing to their enticing features such as high sensitivity, label-free, cost-effective, safer, and remote detection possibilities [9-13].

2.1. Surface functionalization of nanoparticles

The importance of NPs in scientific research, biomedical purposes, and commercial purposes has recently gained much momentum. This increased momentum is attributed to the unique size of NPs, which gives them enticing physiological, biochemical, optical, and electric properties. Increased surface area due to their smaller size further adds to their uniqueness in terms of their use as sensors for different types of chemicals, and environmental, or biological sensing. It is worth mentioning that the shape, dimension, and structure of an NP define its properties and reactivity in a more detailed way. The recognition procedure of surfaces using NPs manages various cellular as well as extracellular processes for different biochemical applications such as inhibition using enzymes, drug delivery,

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biomolecule, micro-organism sensing, and regulation of transcription. The core of NP can be altered depending on the core material used, which opens gateways towards more effective, sensitive sensing of various proteins, vitamins, nucleic acids, and many other biomolecules [14].

3. Drawbacks/limitations

Currently, Nano-research has a wide range of applications that offer numerous advantages for daily use in various fields, such as electronics, medical surgery, lighting, clothes, etc. Even food, packaging, accessories, storage, transportation, and more. all have uses for these nano-based systems. Despite the potential good uses accompanying these technologies, the potential for evil is tremendously high. A crucial system of checks and balances should be maintained to prevent the mishandling of scientific research and capabilities. Regardless of their growth and advancement, several critical considerations on the prevalence of nanotechnology in the world form the basis of ongoing debates. There are anticipated risks and issues that are concerning with several disadvantages. It has evolved the standard of living parallel to increasing the pollution levels in air, soil, water, and food, commonly termed nano-pollution. It is quite hazardous for the biotic components [15].

4. Future of Nanomaterials

Nanotech opens a wonderful window into the upcoming era of bio-mechanics and bio-medicine. Nanomaterials are functional and in continuation of developmental processes. Further, there is plenty of room to be unveiled for prospective ventures with drug delivery systems and cell targeting, which makes them even more competent and effective [16].

Nanomaterials are the cornerstone of the rapidly advancing field of nanotechnology, having the potential to revolutionize diagnostics and therapeutics. The majority of commercially available nanoparticles are geared toward basic medications. Nanoparticles replacing organic dyes require photo-stability and high multiplexing capabilities. Developments in directing and remotely controlling the functions of nanoprobes help drive magnetic nanoparticles to tumor cells, making them release the drug load or heat them to destroy affected cells or cure the diseased cells. Major developments of nonmaterial are to make them multifunctional and controllable by external signals for turning them into nano-devices. There are yet new advancements to be worked upon, especially focused devices with multifunctional operations that can provide medical benefits.

5. Conclusion

Various novel nanomaterials have been used in recent years for innovation in a broad variety of areas, such as biomedical-related applications, disease detection and its cure, environmental and chemical sensing, etc. Health and safety concerns hold much promise for prospects; challenging concerns related to issues of safe and sustainable cofactors are on the agenda list of NIHS. They carry out essential research evaluations and add transformations for safety and material concerns. The National Nanotechnology Initiative has participated in the National Nanotechnology Initiative (NNI), which coordinates the federal government's implementation of the 21st-century Nanotechnology Research and Development Act. These activities account for about 1.3 billion annual total government expenditure.

In extension to the drug delivery mediated system, the important roles of the new armamentarium of therapeutics are pipelines to existing drugs, later improving their efficacy. Various efforts are being put forth to revisit the status of suboptimal but biologically active molecular systems that follow through conventional sources at a prompt pace. Fascinatingly, the attributes of these nano-objects are bestowed to their therapeutic properties, which might be polluting. Hence, fine-tuning of adversities that might occur needs to be lessened. So, more elaborate studies in such sectors for a smarter, faster, eco-friendly, and sustainable system can trounce daunting challenges associated with various platforms.

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