Review Article

FUTURE JOURNAL OF PHARMACEUTICALS AND HEALTH SCIENCES

Published by Pharma Springs Publication Journal Home Page: https://pharmasprings.com/fjphs

Background, Trends, Applications and Therapeutic Approaches of Nanoparticles: A Review

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Article History:

Received on: 26 Oct 2023
Revised on: 01 Nov 2023
Accepted on: 02 Nov 2023

Keywords:

Particle Size,
Nano-technology,
Nanomaterials,
Dendrimers,
Polymeric Nanoparticle,
Carbon Nanotubes

Abstract

The development of nanoscience and nanotechnology in practically every field of science has simplified modern life. Since the arrangement of atoms in structures, electronics and systems produce their distinctive properties and functionalities on the scale of 1-100 nm. Beginning in the early 2000s, there was a rise in public discussion and understanding of the field which prompted the first commercial applications of nanotechnology. Nanotechnologies have a positive impact on almost all fields of study including physics, materials science, chemistry, biology, computer science and engineering. Notably, nanotechnologies have recently been employed with hopeful results to enhance human health, particularly in the field of cancer therapy. Understanding the nature of nanotechnology requires an understanding of the history of scientific discoveries that led to our current understanding of the field.

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eISSN: 2583-116X
DOI: https://doi.org/10.26452/fjphs.v3i4.523

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INTRODUCTION

Over the past ten years, the prefix "nano" has become more and more used in several branches of knowledge. According to the National Nanotechnology Initiative's definition, nanoparticles are objects with at least one-dimensional size between 1 and 100 nm. However, particles up to several dried nanometers in size are frequently referred to as nanoparticles [1]. Nanotechnology is the study of very tiny objects. It involves the usage and tinkering with matter. At this scale, atoms and molecules function differently and provide a wide range of unexpected and fascinating applications [2]. Studies on nanotechnology and nanoscience have exploded during the past several years in a variety of product categories. It offers chances for the creation of materials, especially those for medicinal uses, while more traditional methods could have their limitations [3]. It is incorrect to think about nanotechnology as a single approach that only affects certain fields. Although it is sometimes called the "tiny science" nanotechnology encompasses more than just extremely tiny objects Bulk materials and huge surfaces frequently contain nanoscale characteristics[4]. To create novel nanosized materials, nanotechnology entails the design, manufacture, and use of materials at atomic, molecular, and macromolecular sizes. Pharmaceutical nanoparticles are solid, submicron-sized drug carriers with a diameter of less than 100 nm that may or may not be biodegradable. In contrast to nanocapsules, which have a special polymeric membrane around the drug, nanospheres are matrix systems in which the medication is evenly spread [5]. The classification, production technique, characterisation, use, health implications, and pharmacological features of nanoparticles are the main topics of this holistic review [6]. Physicochemical and biologically enhanced nanocarriers can successfully be employed as delivery vehicles for currently available bioactive substances since they are more readily absorbed by cells than bigger molecules.

As drug delivery methods, nanocarriers such as liposomes, solid lipid nanoparticles, dendrimers, polymers, silicon or carbon compounds, and magnetic nanoparticles have been studied [7-8].

Types of Nanoparticles

Carbon Nanotubes (CNTs)

Carbon nanotubes are a hexagonal network of carbon atoms with a diameter of 1 nm and a length of 100 nm. Single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) are two different forms of CNTs. Carbon nanotubes are special materials because of their tiny dimensions and exceptional physical, mechanical and electrical capabilities. Depending on how the carbon leaf is twisted around itself, it exhibit metallic or semiconductive qualities. Nanotubes are a superconductor due to their extraordinarily high current density, which may approach one billion amperes per square meter [9-10].

Dendrimers

A novel family of controlled-structure polymers with nanometric dimensions is the dendrimers. With many functional groups on its surface, dendrimers are typically 10 to 100 nm in diameter, used in drug administration and imaging provide excellent carriers for targeted drug delivery. Modern dendrimers can be quite specialized, with their cores containing functional molecules (such as medicinal or diagnostic compounds). They are regarded as fundamental building blocks for producing both organic and inorganic nanostructures on a wide scale sizes ranging from 1 to 100 nm. Dendrimers are used in pharmaceutical products such as nonsteroidal anti-inflammatory drugs, prodrugs, anticancer medications, antibacterial, and antiviral medications and screening agents for high-throughput drug discovery [11]. Due to their capacity to damage cell membranes as a result of a positive charge on their surface, dendrimers may be poisonous.

Polymeric Nanoparticles

It's a cutting-edge type of material created by nanomaterials for technical advancements in the delivery of drugs and other healthcare applications [12]. PNPs are produced utilizing synthetic as well as natural polymers in a variety of ways depending on the desired features. The various stimulus effects of these produced PNPs have been demonstrated via research [13].

Solid Lipid Nanoparticle

Solid nanoparticles made from lipids are at the cutting edge of the quickly growing field of the field of nanotechnology with numerous potential uses in health care, delivery of medication, research and other diverse sciences [14]. The in-vivo outcome of the vectors and elements of the SLN administering routes are also covered. In a wide sense, the word "lipid" refers to triglycerides, partial glycerides, fatty acids, hard fats and waxes. The fact that the lipid matrix is composed of endogenous lipids reduces the risk of both acute and long-term toxicity, which is a definite benefit of SLN. It has been demonstrated that using solid lipids rather than fluid lipids improves the stability of included chemically sensitive lipophilic components and increases capacity to regulate the discharge dynamics of encapsulating chemicals [15]. It is particularly needed to employ biodegradable components for intravenous delivery because they avoid the need for surgery to eliminate the insertion after the drug has been released completely and because they make it possible to administer micro and nanoparticles. The idea has been implemented in several business products [16-18].

Gold Nanoparticles

In recent years, there has been a lot of investigation and interest in the field of nanotechnology. The rapid advancement of nanotechnology has led to a remarkable expansion in the production and application of nanoparticles (NPs). One of the most significant tiny particles is gold (AuNPs) and due to their special characteristics, they are a perfect material for both healthcare and other medical uses [17]. The negative impacts of present synthesis techniques have inspired researchers to concentrate on the creation of ecologically friendly and green synthesis employing non-toxic compounds from organic materials such as plant extract, bacteria, and fungi. Microbes can prepare gold nanoparticles internally or externally, however external cell management is simple in terms of insulation. It is recommended to extract gold nanoparticles using modified nanocellulose [18]. In addition to biosensor applications, tumour-targeting ability (Anticancer Activity) for cancer therapy and precise drug delivery of nano-vehicles to sick tissues, AuNPs have demonstrated exceptional applications for diagnostic and therapeutic uses [19].

Silver Nanoparticles

The way to identify and avoid many diseases in all facets of human existence has undergone a major shift because of the latest developments in nanoscience and nanotechnology. Of the many metallic particles used in medical devices, silver nanoparticles (Ag NPs) are one of the most significant and interesting nanomaterials [20].

While many precious metals have been employed for a variety of uses, Ag NPs have received particular attention due to their possibility for use in the treatment and diagnostics of malignancy [21]. Additionally, we go into detail about the numerous biological uses for Ag NPs, such as their use as antiviral, antifungal, antibacterial, anti-allergic, anti-angiogenic, and curative medicines, as well as the process underlying their action. We also talk about the difficulties and treatment strategies for Ag NP-based chemotherapy for cancer. At last, we wrap up by talking about Ag NPs' potential in future generations [22-23].

Nanosponges

The perfect delivery system will make the medicine soluble, transport the therapy to the desired location and then release the treatment as needed to meet the specific needs of the patient and the phase of the disease. Nanosponges are one of the more productive drug delivery systems because they can carry both hydrophilic and hydrophobic medicines which solves the issues related to medication toxicity and low bioavailability [24-25].

Nanosponges are extremely small and have and a three-dimensional system containing nanometric-sized cavities. Nanosponges have a special capacity to hold molecules that are active and have the benefit of programmed liberation. They are easy to make and secure for human use. By using a carbonyl or a dicarboxylate chemical as a cross binder to join several types of cyclodextrins, nanosponges can be created. Nanosponges, a recently created aqueous framework, have a chance to overcome issues with medication harmful effects and decreased the bioavailability and drug distribution over a wide area because they can be modified to work on both hydrophobic and hydrophobic types of drugs [26].

Nanospheres

Nanospheres can be used in a variety of ways, including for drug administration in the brain, long-term circulation purposes and to target cancer cells. There are many ways to make nanospheres but the solvent displacement technique is the most effective. The use of nanotechnology is now frequently employed to focus on malignant cells [27]. Albumin nanospheres, modified starch nanospheres, gelatine nanospheres, polypropylene dextran nanospheres and polylactic acid nanospheres are only a few examples of biodegradable nanospheres. These delivery systems' nano-size range enables them to be directly injected into the systemic circulation without running the danger of obstructing blood vessels. It has been demonstrated that a key determinant of the fate of the nanoparticles in vivo is their size. Particles with a diameter of less than 200 nm have been reported to exhibit a slower rate of clearance and a longer circulation time than those with a larger diameter [28].

Nano Liposomes

The pharmaceutical and food sectors both employ nanoliposomes as a sort of vector. These lipid nanostructures are used in the food industry during the production of food products, particularly to enhance flavour, texture, and food preservation. Nanoliposomes are an intriguing type of carrier for bioactive chemicals due to their natural lipid content and capacity to encapsulate both hydrophobic and hydrophilic substances [29]. In nutraceutical applications, it is possible to envision encapsulating compounds known to have advantageous effects on organs or tissues in these lipid-based vectors to develop functional foods intended to prevent disease. To guarantee excellent digestion and bioavailability, it is required to manage specific parameters during the manufacturing and storage of nanoliposomes to meet this goal. In fact, there are still difficulties in ensuring that nanoliposomes remain stable during storage and after ingestion. There are numerous methods of manufacture, however the durability of nanoliposomes is influenced by the oxidative nature of lipids and their phase transition temperature [30].

Magnetic nanoparticles

Magnetic nanoparticles (MNPs) have proven useful in a variety of fields, including the pharmaceutical, radiological, and biomedical ones. They have improved the accuracy of magnetic resonance and magnetic particle visualization, information technology, and cells creating activities. In addition to these, MNPs have improved medication delivery to difficult-to-reach micro niches as a result, their application in different therapeutic pathways has expanded, with a trend toward the fusion of novel biotechnologies in medical care and remedial contexts emerging [31].

Limitations of Nanoparticles

Solubility

NPS's solubility may vary under specific circumstances, like as different temperatures. The way medicine and NPS interact can be impacted by temperature fluctuations. Certain individuals may experience differing therapeutic effects as a result, which is undesirable for medical therapies [32].

Bioavailability

The drug's bioavailability may vary depending on the amount of Nanoparticles given to the body. As one of the least invasive procedures, the nasal route is the most practical and acceptable.

Blood-Brain Barrier

The blood-brain barrier (BBB) is crucial for the operation of synaptic transmission and neuronal circuits. For a greater number of exogenous substances, it continues to be an insurmountable barrier. NPS is one method of drug administration that can effectively move active molecules across the BBB. This is because NPS has been functionalized with ligands to enhance targeted drug delivery and circumvent BBB. The effectiveness of these ligand-modified NPS, however, has to be examined because it still takes a significant amount of time for them to cross the BBB and reach their intended target system [33-34].

Toxicity

Due to NPS's poor encapsulation effectiveness and loading capacity, consuming large quantities of nanocarriers containing surfactants and cosurfactants can have detrimental effects. Certain NPS that have been injected into the body can be difficult for different clearing systems to remove. This could lead to an accumulation of NPS in the brain system, which would be cytotoxic. The buildup of NPS over time in the brain might cause damage to the brain [35].

Preparation Technique for Nanoparticles

Solvent Evaporation

For the first time, a process was created to design the nanoparticles. In this approach, the nanoemulsion formulation is first made and the polymer is then dissolved in an organic solvent. This solution is used to distribute medication. High-pressure homogenization is used to create an o/w emulsion. After the emulsion is formed, the organic solvent evaporates by raising the temperature and lowering the pressure while stirring continuously.

Emulsification Diffusion

It is a modified version of the technique, the polymer is dissolved in a water-miscible solvent, which is then saturated with water. In an aqueous solution containing a stabilizer, the polymer-water-saturated solvent phase is emulsified, and then the solvent is removed using filtration or evaporation. The high encapsulation efficiency (usually 70%), lack of homogenization, excellent batch-to-batch reproducibility, simplicity, ease of scale-up and limited size distribution of this approach are its benefits.

Nanoprecipitation

This approach involves dissolving a polymer, drug and hydrophobic surfactant in a semi-polar water-miscible solvent, which is then added to a stabilising solution while it is being stirred. Nanoparticles are created as a result of rapid solvent diffusion. Because they interact poorly with polymers, hydrophilic medicines have lower drug loading efficiency than hydrophobic pharmaceuticals because the drug diffuses from the polymers organic phase to the surrounding aqueous environment. The method created core-shell particles that may effectively disseminate poorly water-soluble medicines with reasonable stability during storage. The choice of drug, polymer, solvent, or non-solvent solution in which the nanoparticles would be created and the drug effectively encapsulated presents a challenge in this manufacturing procedure.

Salting-out

This method relies on the salting-out phenomenon to separate the water-miscible solvent from the aqueous solution. This approach avoids the use of hazardous solvents. Since acetone completely dissolves in water and is simple to remove, it is frequently utilized. Salting out can also be achieved by saturating the aqueous phase with colloidal stabilizer/viscosity-increasing agent polyvinyl pyrrolidine. After creating the o/w emulsion, add enough water to dilute it, allowing acetone to completely diffuse into the aqueous phase, resulting in the production of nanospheres.

This method eliminates the need for higher temperatures and more vigorous stirring to get smaller particle sizes.

The methods restriction to lipophilic medications and the time-consuming cleaning procedures for nanoparticles are limitations.

Spray Drying Method

Spray-drying has been frequently utilised to create micron-sized particles. Spray-drying is the process of converting a solution droplet into a dry particle in a single step by evaporating the solvent.

Spray drying has been successful for temperature-sensitive molecules such as proteins and enzymes.

It has been demonstrated that particles composed of various polymers and drugs, both water-soluble and water-insoluble, can be prepared without the problem of drug leakage to another phase and that the particle properties, particularly morphology, can be controlled by solvent properties and spray-drying variables [36].

Nanoparticle Applications

Bone growth stimulants

Researchers used collagen hydrogels and chicken fatal femurs to show the basic concepts of their in vitro technique. Mesenchymal stem cells (MSCs) were microinjected into the femur and tagged with magnetic nanoparticles [37]. The therapy known as bone growth stimulation (BGS) is frequently used to speed up the recovery process following a spinal fusion operation or a fracture. Two categories of BGS exist:

1. Agents that promote internal bone development
2. Bone growth stimulator external

Stimulators for internal bone development are surgically inserted. Portable devices called external development of bones stimulators can be worn outside the body.

Cancer therapies

Small structures of molecules and particles are used as tools in the development of nanotechnology to deliver medications. Nano-carriers utilized in cancer treatment include liposomes, micelles, dendritic macromolecules, quantum early diagnosis and the suppression of the growth and spread of malignant cells are the main goals of cancer diagnostic and treatment approaches [38]. Among the first diagnostic methods for cancer, the use of PET, MRI, CT, and ultrasound is noteworthy. Therapeutics based on nanoparticles can cause tumour cell death, which in turn stimulates the release of neoantigens from the tumour. Nanoparticles can be used to enhance T-cell activation and antigen presentation.

Implant coatings

Coatings that are neutral to biological things and make it easier for non-biological materials to be incorporated into body tissues are known as biocompatible coatings. Due to their excellent mechanical and chemical characteristics along with their biocompatibility, titanium and its related alloys are some of the most widely utilized materials for orthopaedic and implant dentistry [39]. So, for the coating process, Ti-6Al-4V alloy plates were utilized.

Sunscreens

Based on the toxicology, exposure level and chemical makeup of the elements, the development of nanosystems with various substances in their content has been improved. For instance, topical formulations with nanoparticles encapsulating ZnO and TiO2 have a translucent look and in contrast to microparticles can stop skin from becoming lighter after applying sunscreen because they scatter and reflect UV light. As a result, compositions comprising these nano-systems are easier to apply and more acceptable from an aesthetic standpoint. When utilizing nano-sunscreen formulations, biocompatibility, photostability and long-term release are other important factors to take into account.

Biomarking and detection

Nanomaterials have received a lot of interest as a result of the sharp rise in nanotechnology and nanoscience for the purpose of making biological sensors using improved signal quality.

Three goals were accomplished by using nanomaterials in an optical biosensor platform,

1. Enhancing the optical signal
2. Functionalizing the transducer support and effectively immobilizing the biorecognition element
3. Improving the specific surface area for immobilizing the biomolecules

High specificity, responsiveness, and the capacity to perform several target evaluations simultaneously are all provided by nanoparticles. Nanoparticles and nanomaterials can be used to enhance biosensors to offer exact targeting [40].

Modern composites for teeth

Since sapphire 12 and diamond have 20–100 times the hardness of enamel, replacing the surface dental coating with these substances may improve the teeth's durability and aesthetics. Although fragile, diamonds and sapphires can be strengthened by being included in a nanostructured material composite. Dental professionals place a strong emphasis on limiting tooth decay by suppressing caries by managing biofilm, promoting revitalization or providing the oral cavity with antimicrobial protection. As a result, nanotechnologists are constantly attempting to develop new, effective solutions. The casein phosphor-peptides work as analogous compounds to reduce microbial adhesion by binding to the surfaces of microorganisms and stabilizing calcium and phosphate ions through the creation of crystalline calcium phosphates. Metals have also long been researched for their potential antibacterial properties. Because of its antibacterial characteristics, standard goods frequently contain zinc oxide (ZnO).

Biological binders

While generated by humans nanostructures get the majority of attention in nanotechnology investigations, genuine nanostructures have existed for countless years. An assemblage of molecules or atoms created in a biological system and having at least one dimension between 1 and 100 nm is considered a naturally produced nanoparticle. These microscopic particles include exogenous complexes like viruses and lipoproteins as well as intracellular structures like magnetosomes. They serve a variety of purposes, from serving as intercellular messengers to serving as mineral storage facilities [41].

CONCLUSION

Nanoparticles have exceptional properties that have recently made them significant in a range of areas such as energy, health care, the environment, agriculture and so on. Nanotechnology applications can convert unstable, poorly soluble and poorly absorbed physiologically active molecules into viable deliverable chemicals, demonstrating their significant promise. The use of nanoparticles for targeted medication delivery has advanced greatly due to excellent applications, minimising the shortcomings of standard drug delivery systems. Many nanomaterial types are being explored for the targeted administration of medications.

ACKNOWLEDGMENT

The authors wish to extend their heartfelt gratitude to management Srmt. A. Sumalatha, Seven Hills College of Pharmacy, (Autonomous), Tirupati for providing all kinds of facilities.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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