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The Nanorevolution in Drug Delivery: A Review Of Nanoparticles as DDS

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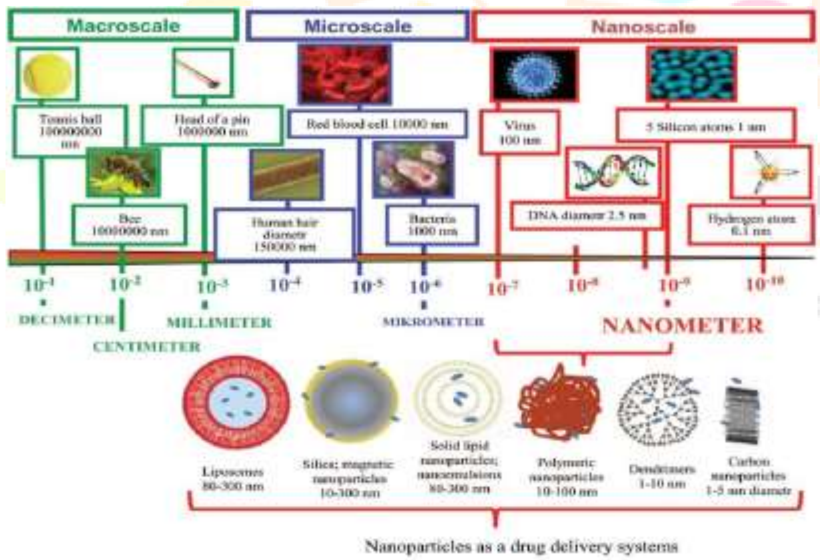
Abstract

As a promising approach for targeted medication delivery, nanoparticles as drug delivery systems (DDS) have transformed pharmaceutical sciences. This review paper offers a thorough analysis of nanoparticles as DDS, stressing their benefits, drawbacks, and uses in a range of illnesses, such as neurological conditions, infectious diseases, and cancer. We summarize the existing state of knowledge and outline future directions for nanoparticle-based DDS by discussing the current status, classification, preparation techniques, targeting strategies, toxicity concerns, regulatory considerations, and future perspectives of nanoparticles as DDS.

Keywords-Nanoparticles , Drug Delivery System, Targeted drug delivery, pharmaceutical sciences, infectious disease, Neurological disorders, Nanotechnology,Drug development, Personalized medicine.

I.Introduction

The science of nanotechnology looks at matter at a billionth of a meter (i.e., 10 – 9 m = 1 nm) and studies how to manipulate matter at the atomic and molecular level. A nanoparticle, the most basic building block of a nanostructure, is larger than an atom or a simple molecule, which are subject to quantum mechanics, but much smaller than the world of common things, which are characterized by Newton's laws of motion. The National Nanotechnology Initiative (NNI) was established by the US in 2000, and in 2001, numerous nanotechnology projects were launched across almost all US Departments and Agencies.Approximately 20 Research Centers were subsequently sponsored by the National scientific Foundation (NSF), an organization that reports exclusively to the President of the United States and is tasked with providing funding for the most promising basic scientific and technology initiatives. Leading the U.S. agency in implementing the NNI was NSF. The term "nanotechnology" quickly captured the interest of the general public as well as the attention of TV networks, the internet, and others.The size of a nanoparticle typically falls between 1 and 100 nm. (1)A significant challenge in the treatment of many diseases is getting therapeutic compounds to the intended location. Typical drug applications are characterized by low selectivity, poor biodistribution, and limited effectiveness. (2)The development of nanotechnology has enormous potential to further biomedical research. Every aspect of life is impacted by nanotechnology, from drug delivery systems to nanoscale devices. Because nanocarriers can prevent a drug from degrading by avoiding the reticuloendothelial framework, using nanotechnology for drug transportation appears to be a wise strategy for site-specific drug molecule delivery. The high blood flow profile increases the availability of medication at the targeted intracellular compartments and facilitates transit via biological barriers. (3)This is a summary of the existing drug delivery systems (DDS), beginning with the different drug administration methods. Following that, a variety of medication formulations and tailored drug delivery devices are presented. The number of novel treatments based on biotechnology has significantly increased. Delivering proteins and peptides, which make up the majority of them, is particularly difficult. Gene and cell treatments are advanced ways to provide medications. Nanoparticles, which can be used in both pharmacological and diagnostic applications, are thought to be crucial in improving medication delivery. (4)The need to specifically target the cells involved in the onset and progression of diseases has arisen due to advancements in molecular pharmacology and a better knowledge of the mechanisms behind the majority of diseases. This is particularly true for the majority of serious illnesses that call for treatment medicines with a wide range of adverse effects, necessitating precise tissue targeting to reduce systemic exposure. Modern drug delivery systems (DDS) are designed using cutting-edge technology to maximize treatment efficacy and reduce off-target accumulation in the body by speeding systemic drug delivery to the precise target site. They therefore have a significant impact on the management and treatment of disease. Because of their improved performance, automation, accuracy, and efficacy, recent DDS provide more benefits than traditional drug delivery methods.They are composed of nanomaterials or miniature devices with multipurpose parts that are biocompatible, biodegradable, and possess a high degree of viscoelasticity and a long half-life in circulation. (5)



II.Classification of nanoparticles

1.Organic nanoparticles

Ferritin, liposomes, dendrimers, and micelles are examples of organic nanoparticles or polymers. Known as nanocapsules, these nanoparticles are biodegradable, non-toxic, and sensitive to thermal and electromagnetic radiation, including light and heat. Micelles and liposomes, for example, have a hollow center (Figure 1). (6)

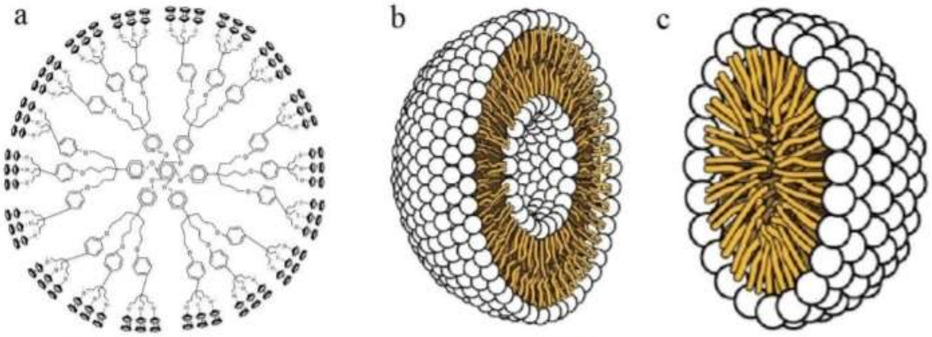


Figure 1. Organic nanoparticles: a – Dendrimers, b – Liposomes and c – micelles.

Features consist of: Applications: Low toxicity, biodegradability, and biocompatibility Targeting and delivering drugs; transfection and gene therapy.

2.Inorganic nanoparticles

Particles that are not composed of carbon are known as inorganic nanoparticles. In general, metal and metal oxide-based nanoparticles are categorized as inorganic. (7)

2.1 Based on metal. Metal-based nanoparticles are created by synthesizing metals into nanometric sizes using either constructive or destructive techniques. It is possible to synthesize nearly all metals into their nanoparticles. (8)The metals aluminum (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag), and zinc (Zn) are frequently utilized in the creation of nanoparticles. Sizes as small as 10 to 100 nm, surface features like a high surface area to volume ratio, pore size, surface charge, and surface charge density, crystalline and amorphous structures, spherical and cylindrical shapes, color, reactivity, and sensitivity to environmental factors like air, moisture, heat, and sunlight are just a few of the unique characteristics of the nanoparticles.

2.2 Based on metal oxides. In order to alter the characteristics of their respective metal-based nanoparticles, metal oxide-based nanoparticles are synthesized. For instance, iron (Fe) nanoparticles at room temperature instantly oxidize to iron oxide ($Fe2O3$) when oxygen is present, increasing their reactivity in comparison to iron nanoparticles. The primary reason for the manufacture of metal oxide nanoparticles is their enhanced efficiency and reactivity. (9)The most often produced are aluminum oxide ($Al2O3$),Iron oxide ($Fe2O3$), magnetite ($Fe3O4$), silicon dioxide ($SiO2$), titanium oxide ($TiO2$), zinc oxide (ZnO), and cerium oxide ($CeO2$). When compared to their metal counterparts, these nanoparticles show remarkable qualities.

2.3 Carbon-based The term “carbon-based” refers to nanoparticles that are entirely composed of carbon. (10) They are shown in Figure 2 and can be divided into fullerenes, graphene, carbon nanotubes (CNT), carbon nanofibers, carbon black, and occasionally activated carbon in nanosize.

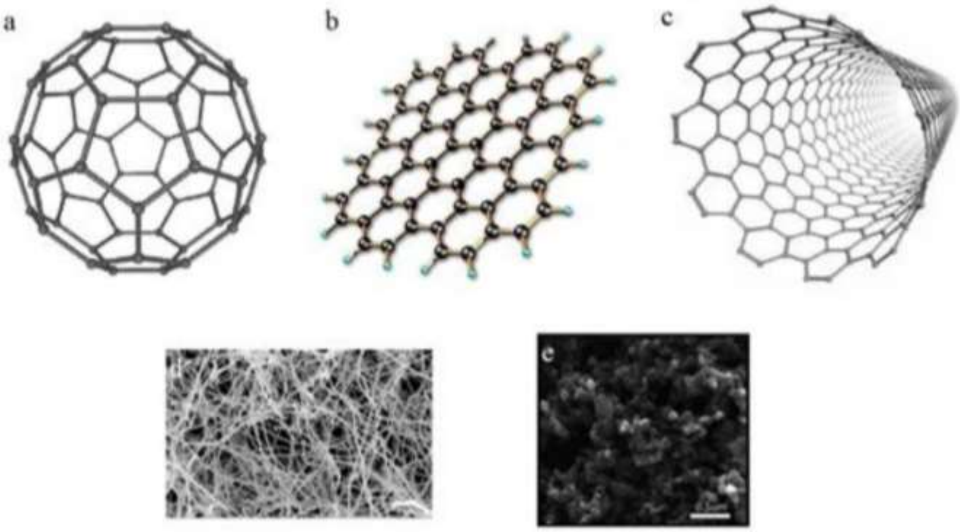


Figure 2. Carbon based nanoparticles: a – fullerenes, b – graphene, c – carbon nanotubes, d – carbon nanofibers and e – carbon black

III.Methods for the synthesis of nano materials

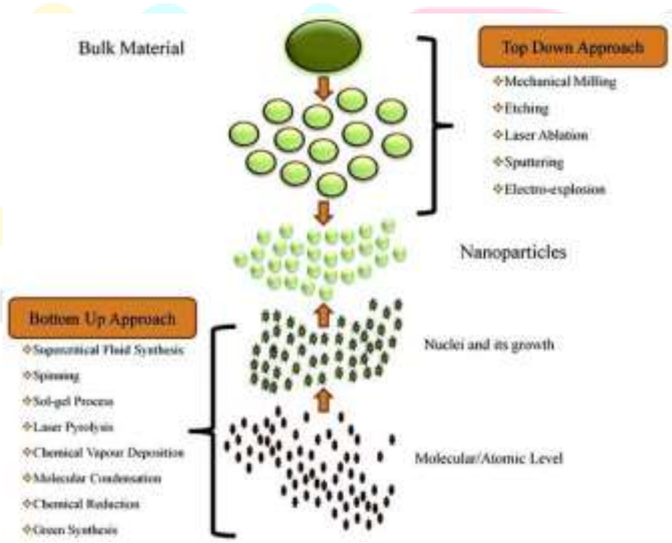
There are two primary methods for creating nanomaterials (Fig. 1): top-down and bottom-up methods. Figure 1: Top-down and bottom-up methods for creating nanomaterials. (11)

1.Top-down methods

Top-down methods Top-down methods create nanostructured materials by dividing bulk materials. Mechanical milling, laser ablation, etching, sputtering, and electro-explosion are examples of top-down techniques. (11)

2.Bottom methods

Using atomic or molecular building blocks, bottom-up approaches create nanoparticles. Sol-gel procedures, chemical vapor deposition, and self-assembly are among the methods.



IV.Targeting Strategies

1.Passive targeting

The increased permeability and retention (EPR) effect is one physiological feature that passive targeting uses to build up nanoparticles at the target location.

EPR Effect: Nanoparticles can collect specifically in tumors due to the poor lymphatic drainage and leaky vasculature found in tumor tissues. Applications include the treatment of infections, inflammatory areas, and cancer. (12)

2.Active targeting

Adding particular ligands to nanoparticles that bind to receptors that are overexpressed at the target region is known as active targeting.

Ligand-Receptor Interactions: To improve selectivity, nanoparticles can be coupled with antibodies, peptides, aptamers, or small molecules like folic acid.

For instance: Nanoparticles that target HER2 for the treatment of breast cancer. Nanoparticles conjugated with folate for targeting cancerous cells. (13)

3.Physical targeting

This method directs nanoparticles to the target location using outside stimuli.

Magnetic Targeting: An external magnetic field is used to guide magnetic nanoparticles, such as iron oxide, to particular areas.

Thermal Targeting: When subjected to heat (such as near-infrared light), thermosensitive nanoparticles release medications. (14) (15)

V.Applications

1.Treatment for Cancer

By enhancing targeted delivery and lowering systemic toxicity, nanoparticles improve the therapeutic efficiency of anticancer medications.

1.1Liposomal Nanoparticles: Providing controlled release and less cardiotoxicity, liposomal doxorubicin is used to treat breast and ovarian cancer.

1.2Polymeric Nanoparticles: In lung cancer, NPs based on poly(lactic-co-glycolic acid) (PLGA) improve the administration of paclitaxel. Through localized heating, gold nanoparticles allow for tumor ablation in photothermal therapy. (16)

2.Infectious Diseases

Diseases That Spread By increasing medication penetration and decreasing resistance mechanisms, NPs increase antibacterial effectiveness. Silver nanoparticles are being investigated for wound infections because of their broad-spectrum antibacterial qualities. Chitosan nanoparticles are useful for delivering antiviral medications through the mucosa and enhancing their bioavailability against HIV. (liposomal amphotericin B) is a liposome-based antibiotic that has a lower nephrotoxicity and is used to treat fungal infections. (17)

3.Disorders of the Nervous System

NPs improve the treatment of brain cancers and neurodegenerative illnesses by facilitating drug distribution across the blood-brain barrier (BBB).

3.1Polymeric Nanoparticles: In Parkinson's disease, PEGylated PLGA NPs improve levodopa administration.

3.2Lipid nanoparticles: Used in Alzheimer's disease treatments based on siRNA. Gold nanoparticles are being researched for glioblastoma treatment's tailored imaging and medication delivery. (18)

4.Eye Conditions

Nanoparticles enhance the treatment of retinal and corneal disorders by improving ocular medication retention.

4.1Nanomicelles: In dry eye illness, cyclosporine-loaded nanomicelles improve ocular bioavailability. PLGA-based polymeric nanoparticles (NPs) enhance the intraocular administration of dexamethasone for uveitis

4.2Lipid-Based Nanoparticles: When treating age-related macular degeneration, solid lipid nanoparticles improve the delivery of anti-VEGF medications. (19)

VI.Future Prospects

Nanocarriers can now recruit candidates for upcoming projects involving tailored medicine delivery thanks to developments in nanoparticle surface technology. In terms of sickness diagnosis, prevention, and treatment, the application of nanotechnology in medicine has a significant impact on human health. Many forms of cancer are presently diagnosed and/or treated by nanocarriers, many of which have been approved for clinical use. Furthermore, there are other formulations that are now undergoing various phases of clinical studies.

Nanocarriers are designed to distribute medications using a variety of methods, including triggered release, solubilization, active targeting, and passive targeting. Nanocarriers reduce the risk of systemic, negative effects, boost therapeutic efficacy, and lower the effective dose. Biological challenges, large-scale manufacturing, biocompatibility and protection, intellectual activity, regulatory regulations, and overall cost effectiveness in comparison to existing treatments were among the main issues raised in the clinical development of nanocarriers. It is advised to develop a customized nanomedicine treatment strategy based on the unique genetic and disease profiles of each patient. Researchers should think about simplifying nanocarriers and taking into account the ultimate dose form for human consumption in order to make the formulation suitable for therapeutic usage.

Challenges in toxicology arise when nanodrugs build up in undesirable tissues. Therefore, determining the biological distribution of nanoparticles following systemic injection should be taken into account in clinical research. With a number of successful late-stage clinical trials, nanocarriers have recently been extensively studied in vaccines against SARS-CoV-2, which causes COVID-19. Businesses like Moderna and BioNTech package mRNA, which encrypts for a COVID-19 allergen, using nanocarriers. Moderna and BioNTech/Pfizer have requested urgent user permission after meeting their primary effectiveness cut-offs in phase III clinical trials since November 30, 2020. (20)

Conclusion

When it comes to enhancing drug delivery, nanoparticles have shown to be a flexible and effective technique. The potential of nanoparticles to cure a wide range of illnesses, such as cancer, infectious diseases, and neurological conditions, has been demonstrated by their capacity to target certain areas, regulate release, and enhance bioavailability. The future of nanoparticles as DDS appears bright, despite a number of obstacles, including as toxicity and safety issues, regulatory barriers, and scalability problems. As research progresses, we anticipate the creation of increasingly complex nanoparticles and DDS, which will ultimately improve patient outcomes globally.

Aknwoledgment

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