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Research article

Nanoparticles as a drug delivery system: physicochemical properties, disease treatment

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ABSTRACT

Due to the quick process in nanotechnology, the medical field has been using nanomaterials a lot recently. Because they have qualities, such as tiny size, adjustable surfaces, and strong bonding with other molecules, they are both water-loving and water-hating. They are ideally prepared for target-specific and controlled delivery of micro and macromolecules in the disease state. They have an outstanding performance towards bioavailability, bio-efficacy and pharmacokinetics. Nanotechnology has a great impact on the global economy and global standards of living. Nanotechnology has revolutionised all aspects of daily living, from the medical industry to the food industry. This review summarises the characteristics of nanoparticles that have potentially toxic effects. The applications in other biological fields and the nanoparticle drug delivery system in disease treatment.

Keywords: Nanotechnology, liposomes, nanoparticles.

INTRODUCTION

Nanotechnology involves purposely designing and changing tiny bits of materials, measuring from 1 to 100 nanometres, so they can be put together or rebuilt into a better working nano–system [1]. Nanoparticles are tiny particles created when we change matter using technology. They are only slightly bigger than an atom because they are made by shaping molecules. These particles are very useful because they have improved features like being stable on their own and having certain qualities, such as a large surface area, which is much bigger than what regular materials have.

Nanotechnology is a science that is growing very quickly, making big progress in many different uses. Right now, the best nanotechnology is used in many areas like electronics, power, materials science, and medicine.in tiny transistors and parts to make devices smaller, quickers, and less powers. for energy, nanotechnology help create new materials and tools for changing sunlight into power and storing energy .in medicine nanotechnology is used to make new ways to find illnesses, treat them, and grow new body parts .in generals, nanotechnology today is a lively and fast-changing field, with many promising discoveries and uses still to come [2-3]. Nanotechnology is a fast-growing area of research and development encompassing a wide range of areas. They developed in electronics, in energy, in biomedicine, and in nanotechnology is used for new diagnostic tools, therapies, and tissue engineering strategies.

Nanoparticles and nanomaterials are gaining attention for their potential uses in the field of medicine. A particularly promising area is drug delivery. where nanoparticles serve as vehicles to transport medication directly to targeted cells or tissues in the body. These nanoparticles enable them to specifically target unhealthy cells while sparing healthy ones, thereby enhancing effectiveness and minimising the side effects associated with drugs [4].

Nanomaterials can be used in generative medicines to create scaffolds for tissue engineering to transport growth factors and other signalling molecules that promote tissue repair and regeneration. Further controlled cargo release from nanoparticles can be engineered for long-term sustained drug delivery [5-7].

In this review, we are looking briefly at the nanotechnology in selected biological fields with a focus on medicine and the concept of nanoparticles in drug delivery systems for disease treatment.

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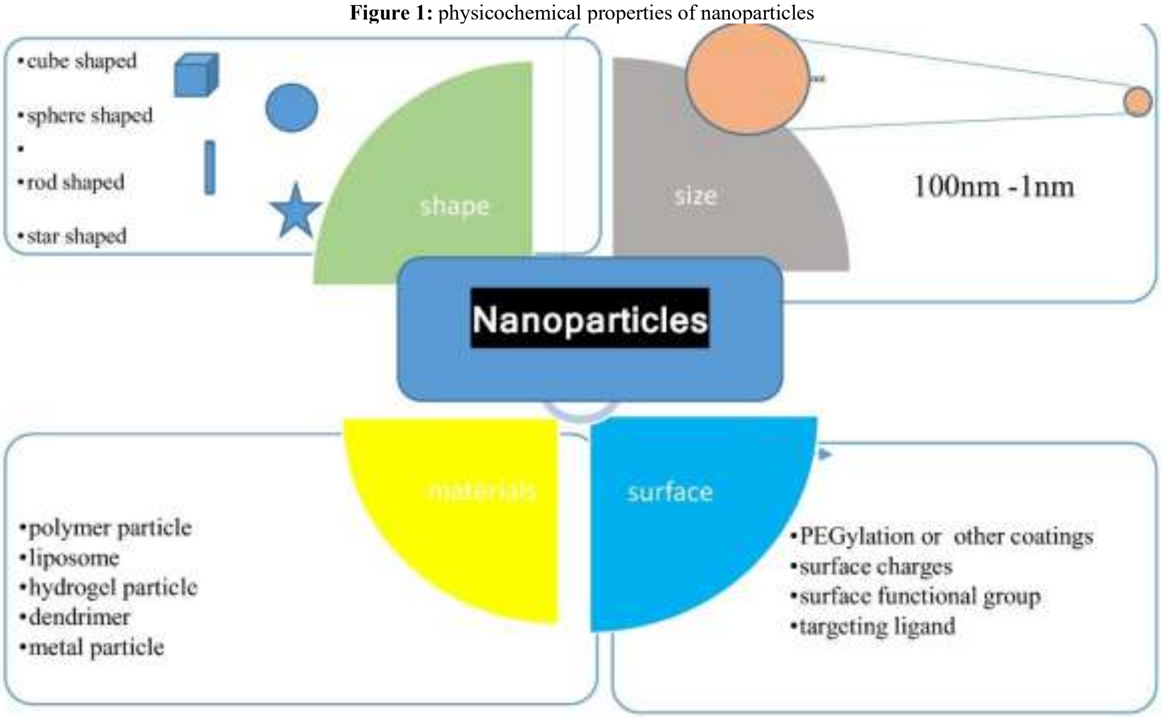
Physicochemical properties of nanoparticles in medicines

Nanoparticles are colloidal materials with particle sizes typically ranging from 1 to 100nm. Due to their unique physicochemical characteristics, nanoparticles have attracted significant attention in pharmaceutical research, especially in drug delivery systems. (Figure 1)

The physicochemical properties include size, surface charge, crystallinity, and surface chemistry.

Below is the detailed description of various physicochemical properties that influence functionality in drug delivery applications [8-10].

Figure 1: physicochemical properties of nanoparticles



Particle size

Particle size refers to the mean diameter of the nanoparticle, while size distribution indicates the uniformity (polydispersity) of the particle population.

Absorption and cellular uptake: Smaller nanoparticles (<200nm) are easily taken up by cells through endocytosis and can cross biological barriers such as the blood –brain barrier (BBB).

Biodistribution: particle size influences how nanoparticles circulate and accumulate in tissues.

Nanoparticles <100nm exhibit prolonged circulation and improved tumour targeting, the enhanced permeability and retention effect.

Larger particles (>200nm) are quickly cleared by the reticuloendothelial system(RES) or macrophages.

Drug release rate: Smaller nanoparticles have a larger surface-to-volume ratio, leading to faster drug release [11-15].

Measurement techniques

Dynamic light scattering (DLS): measures hydrodynamic diameter in suspension.

Transmission Electron Microscopy (TEM): provides high – resolution size and shape analysis.

Scanning Electron Microscopy (SEM): Determines surface morphology and approximate size.

Surface charge (zeta potential)

Zeta potential is the electrical potential developed at the interface between the nanoparticles' surface and the surrounding dispersion medium.

Colloidal stability: particles with high zeta potential (either positive or negative) repel each other, preventing aggregation. A value of 30 mV generally indicates good stability.

Cellular interaction: positively charged nanoparticles interact strongly with negatively charged cell mambranes enhancing cellular uptake.

Shape and morphology

Nanoparticles can be spherical, rod-shaped, cubic, tubular or irregular, depending on the synthesis method and materials used.

Significance

Cellular uptake: spherical nanoparticles are generally internalised faster than rod-shaped ones

Bio distribution and Clearance: shape affects blood circulation time.

Rod-shaped or elongated nanoparticles show prolonged circulation and reduced renal clearance.

Drug loading: morphology can influence the surface area available for drug adsorption.

Measurement

TEM and SEM: determine the exact shape and surface texture of nanoparticles.

Surface Area and Porosity

Surface area is the total exposed area of nanoparticles, while porosity refers to the presence and size of pores within them [9-14].

Importance

A higher surface area allows greater drug adsorption or encapsulation efficiency.

Porous nanoparticles provide controlled drug diffusion and release profiles.

Porosity also influences drug loading capacity and interaction with biological fluids.

Measurement

BET (Brunauer-Emmett-Teller) analysis using nitrogen adsorption-desorption isotherms.

Surface chemistry and functionalization

Surface chemistry defines the composition, type, and nature of chemical groups present on the nanoparticle surface.

determines hydrophilicity, hydrophobicity, and reactivity

functionalizing with specific ligands (eg, antibodies, peptides, folic acid).

PEGylation (attachment of polyethene glycol) is a common modification to improve stability, circulation time, and reduce recognition [15-19].

Table 1: Summary table of physiological properties of nanoparticles

PROPERTY	Key impact of drug delivery	measurement technique
Particle size	Biodistribution, release rate	DLS, TEM, SEM
Zeta potential	Stability, cell interaction, and cellular uptake	Zetasizer, electrophoretic light scattering
Shape and morphology	Cellular uptake, drug loading, prolonged circulation	TEM, SEM
Surface area	Drug loading, solubility, and interaction with biological fluids	BET (Brunauer-Emmett-Teller)
Surface chemistry	targeted drug delivery, reduce immune recognition, release kinetics	FTIR, XPS, NMR

Types of nanoparticles

They can be from metals, polymers, lipids, or other materials and are used for diagnostics, imaging and therapy.

Table 2 : Chart of types of nanoparticles

Types	Composition	Applications
Polymeric	PLA, PLGA, chitosan	Sustained-release vaccines
Lipid based	Phospholipids, lipids	Drug delivery, cosmetics
Metallic	Gold, silver, and iron oxide	Cancer therapy, imaging
Dendrimers	Polyamidoamine (PAMAM)	Targeted drug delivery

Types of nanoparticles

Polymeric nanoparticles

Made from biodegradable polymers such as PLA, PLGA, or chitosan.Can encapsulates both hydrophilic and hydrophobic drugs.

Types

Nanoparticles: solids matrix with a drug dispersed inside.

Nanoparticles: a drug enclosed in a core surrounded by a polymer shell.

Lipid-based nanoparticles

Used widely in pharmaceutical formulations.

Liposomes

Spherical vesicles with phospholipid bilayers.

Can carry both water-soluble and fat-soluble drugs

Solid lipid nanoparticles (SLNs)

Made of solid lipids stabilised by surfactant. It provides controlled release and improved drug stability. A nanoparticle drug delivery system is used for disease treatment.

Nanoparticles have small sizes, and their surface chemistry is very beneficial in pharmaceutical applications, but they also cause **some** toxic effects when released into the body. The therapeutic activity depends on the smaller size of the nanoparticles as compared to large particles because they have more retention in the body, and at the time of elimination, more drug is released out of the body without showing any therapeutic activity. Some typical DDs are researched and developed in various treatments of diseases [20-24].

Lipid bases dss

These are made up of lipids formulation it consists mainly two parts: 1. Micelles, 2. Liposomes. Micelles are formed through a single layer of lipid molecules in aqeous environment they are used to successfully transport hydrophobic molecules or at concentrations above inherent water solubility Just like micelles, liposomes are hydrophobic drugs that carry water-hating or oily outer layers by linking with fatty parts of their building blocks. Water-loving substances like DNA or crystal drugs can be held inside their watery centre [25-29].

Changes can now be made to the outside of liposomes to help drugs work better in the body, as seen with PEG. Drugs can be attached to the surface using electrical attraction or by joining them with other substances like antibodies, cancer treatment, small protein chains, and other proteins. This helps drugs to deliver to specific places and is often done using connecting tools like avidin-biotin pairs, PEG, or peptide connectors that are chemically joined to the liposome's outer part and to the chosen drug. Liposomes usually don't last long in the body, but new drug delivery studies have found a way to make it last longer.

Polymeric DSSs

Polymer nanoparticles which are made of repeating polymer units have been extensively studied for medical uses recently common polymeric drugs delivery system include PEG, chitosan, PLGA, and PLA among these PEG , PLGA, PLA are most frequently researched but chitosan is gaining popularity because it is safe for the body (19,20)doesn't cause a strong poisonous many drugs attached to PEG the most common polymer DSS used commercially. However, PLGA and PLA often release a lot of their stored drug quickly, regardless of where the drug is meant to go. This can lead to too much drug going to the wrong places, which reduces how well the drug works. Because of this, scientists have created polymer DSSs that release drugs when triggered by things like small changes in pH or the production of reactive oxygen species in the body. Polymer-based DSS seems to be less flexible and less technical in terms of targeting the tumour microenvironment [30-34].

Summary and future aspects

Summary

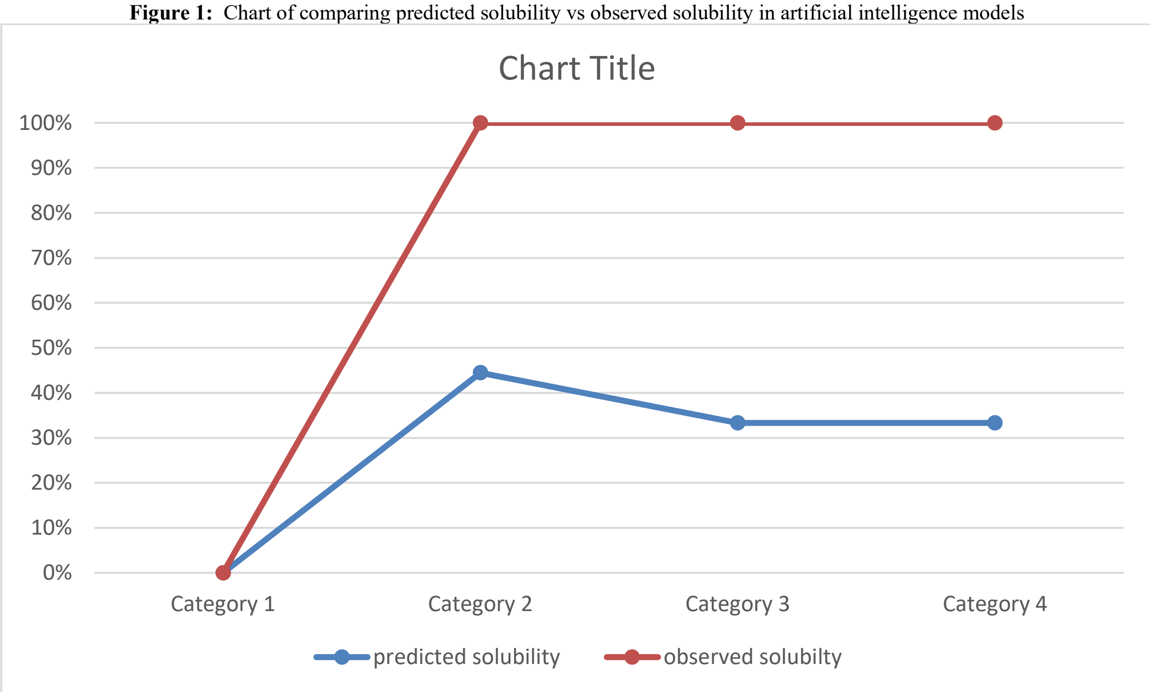
Because of tremendous contributions made to the fields of medicine, food, cosmetics and personal care, nanotechnology has improved our understanding of the world. These advancements have also contributed to the work of nanotechnology worldwide markets increasing its viability and economic impact globally. Given the medical uses the number of traditional medications with harmful side effects like 7doxorubicin, has been effectively given in doses inside nano carriers, avoiding side effects that would otherwise restrict their uses. Despite all of these advantages, there are drawbacks. Because of their large surface area and surface chemistry nanoparticle are frequently very reactive. There are several ways that nanoparticles enter the environment, including through domestic and commercial sources.

Future aspect in nanotechnology drug delivery systems

Nowadays, nanotechnology is introduced with new sources of artificial intelligence AI. Scientists have approached artificial intelligence into the drug delivery system. (28)to make it more targeted and advanced as compared to a traditional drug delivery system. AI have the properties that significantly enhance the ability of drug solubility, stability prediction, which helps in reducing the prolonged laboratory research. For example. Structure-activity relationship models, machine learning, etc.

AI plays an important role in the system optimisation and modelling of drug release patterns and improved formulations. AI helps in forecasting of the physiological environment, such as fluctuations in pH and temperature, allowing scientists to study drug release kinetics.

Figure 1: Chart of comparing predicted solubility vs observed solubility in artificial intelligence models



The future perspectives of AI integrate with nanotechnology and 3d printing holds immense potential for the future of drug delivery.

Wearable devices are made for monitoring the patient's health in real time.

AI models can predict the success rate of clinical trials and identify potential risks.

The system analyses data to identify the most suitable candidates and optimises the trial production [35-40].

CONCLUSION

In conclusion, nanotechnology has a large perspective in all aspects of our day-to-day life. The nanoparticles have their physicochemical properties and different uses of nanoparticles in disease treatment. It faces the challenges against toxicity, biomedicine, clearance and stability. Which can be overcome through many researches. Nanotechnology is taking a new step with the use of artificial intelligence, which makes it easier for patient compliance and laboratory studies. Lastly, nanotechnology is still under development and poses challenges to research companies.

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