Life Sci. Res. Commn., 2026; 2(1):1-6.
https://lifesci.com.sg

Review Article

Overview of Nanotechnology in Drug Delivery Systems

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ABSTRACT

One area that nanotechnology has benefited the modern medicine is in the field of surgery advancement in the Drug Delivery Systems (DDS). Nanocarriers make targeted, controlled, and effective administration of therapeutic agents, and hence, improved efficacy and reduced side effects. This review addresses the different varieties of nanocarriers, their action mechanisms, and use in different medical disciplines, and the problems of clinical translation. We put emphasis on future and recent progress viewpoints, with the focus on how nanotechnology can transform personalized medicine.

Keywords: Advanced drug delivery system, Drug delivery system, Nanocarriers, Nanotechnology, Novel drug delivery system.

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Received: 13-01-2026;
Revised: 06-03-2026;
Accepted: 28-05-2026.

INTRODUCTION

Introduction of Nanotechnology in Medicine

The next step of using materials on the level of atoms, molecules, and supramolecules is nanotechnology. In the context of the healthcare process, nanotechnology has been identified to have potential influence in medication delivery where nanomaterials are capable of significant enhancement of efficiency, precision, and targeting in therapies (Nasrollahzadeh, 2019).

Drug Delivery Systems (DDS) are a necessity for the delivery of therapeutic agents to specific locations in the body. Drug delivery systems often have issues with bioavailability and targeting. Nanotechnology has the potential to tackle those issues (Doran, 2019).

Nanotechnology's Role in Enhancing Drug Delivery

Nanomaterials are of a small size, large surface area, and unique physical properties that allow them to interact with biological systems in ways that larger objects could never do. Nanomaterials have the potential to reach areas of the body where larger materials and materials with larger vesicle size cannot access. Moreover, nanomaterials can cross bio membranes, such as the blood-brain barrier and target delivery of drugs exactly where the drug is needed most (Kango, 2013). The Figure 1 suggests the difference between conventional and nano drug delivery.

Mechanisms of Nanotechnology in Drug Delivery

Targeted Drug Delivery

Nanoparticle characteristics can be modified to target specific tissues or cells, minimizing exposure to healthy tissue, and subsequently minimizing side effects. Site-targeted delivery can be accomplished through chemical or biological modifications of the nanoparticle surface, which could include: surface modifications that constrain circulation time in the body, ligands, antibodies, or other chemical moieties that bind to receptors that are overexpressed in the target cells (e.g., cancer line cells) (Kango, 2013).

Controlled Release Systems

Nanoparticles have the ability to be engineered for controlled and sustained release of drugs, either via time-dependent mechanisms or stimuli-responsive methods. For example, nanoparticles can release drugs only when the pH, enzymes, or temperature are conducive to the drug being released thus allowing for an extended period of therapy (Hallan, 2017).

Enhanced Permeability and Retention (EPR) Effect

Cancers, in the majority of instances, develop leaky blood vessels. Due to their small size, nanoparticles can effectively accumulate in this tissue compared to the standard sized particle and thus allow for a greater concentration of drug at the tissue sites. This property of leaky blood vessels has been exploited in cancer therapy (Lu, 2021). Figure 2 suggests mechanism of nanocarrier drug delivery.

OPEN ACCESS

DOI: 10.5530/lsrc.2.1.1

Types of Nanomaterials Used in Drug Delivery

Liposomes

Liposomes are spherical structures, made up of lipid bilayers, acting to encapsulate both hydrophilic and hydrophobic drugs. In addition to delivery, liposomes also serve to protect the drug from degradation and release in a controlled manner. Liposomes are widely used in cancer and vaccine therapy (Davis, 2016).

Micelles

Micelles are amphiphilic molecules with a hydrophobic core and a hydrophilic shell, which allow for delivery of poorly soluble drugs in water. The amphiphilic nature provides an increased solubility and bioavailability profile of drugs (Fatin, 2014). The Figure 3 represents the difference between hydrophobic and hydrophilic drug encapsulation.

Dendrimers

Dendrimers are very branched tree-shaped polymers with a known symmetrical structure. They are having the ability to enclose drugs, or even genes, and deliver them in a regulated way. They can also undergo modification on their surface with extra functional groups to increase biocompatibility and targeting precision (Lu, 2021).

Solid Lipid Nanoparticles (SLNs)

SLNs consist of solid lipid and they are employed in enhancing drug formulations. SLNs are able to entrap hydrophilic and lipophilic drug preparations, and they have prolonged release profiles and, therefore, can be used chronically (Hallan, 2017).

Carbon Nanotubes and Other Nanomaterials

Carbon Nanotubes (CNTs) exhibit a high surface area and can be formulated to carry both small molecules, and larger biomolecules. Other nanomaterials, such as graphene oxide, are also being evaluated (Kango, 2013). Figure 4 represents the structural representation of major nanocarriers.

Applications of Nanotechnology in Drug Delivery

Cancer Therapy

Nanoparticles enable localized therapy which is chemotherapy applied to the location of tumor and minimizing chemotherapy effects on the rest of the body systemic toxic effects. Such targeted killing produces better results and harms less healthy people cells versus conventional chemotherapies (Lu, 2021).

Gene Therapy

Nanotechnology consists of the method to transfer genetic material (DNA/RNA) to cells, which is an essential quality of gene therapy. Formulated nanoparticles are able to shield the

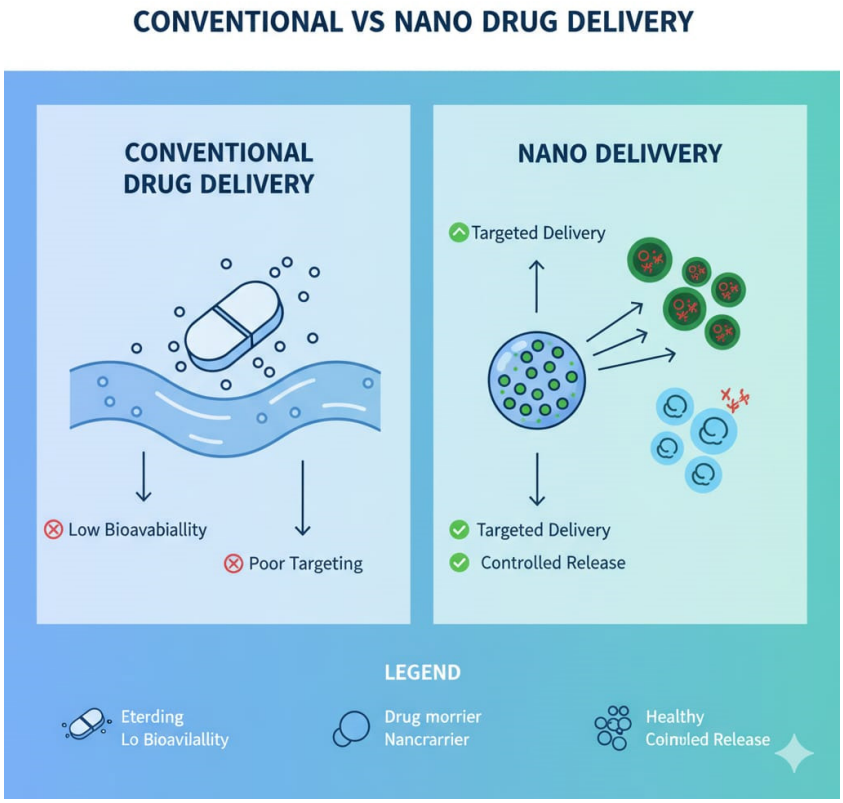

Figure 1: Conventional Vs Nano Drug Delivery.

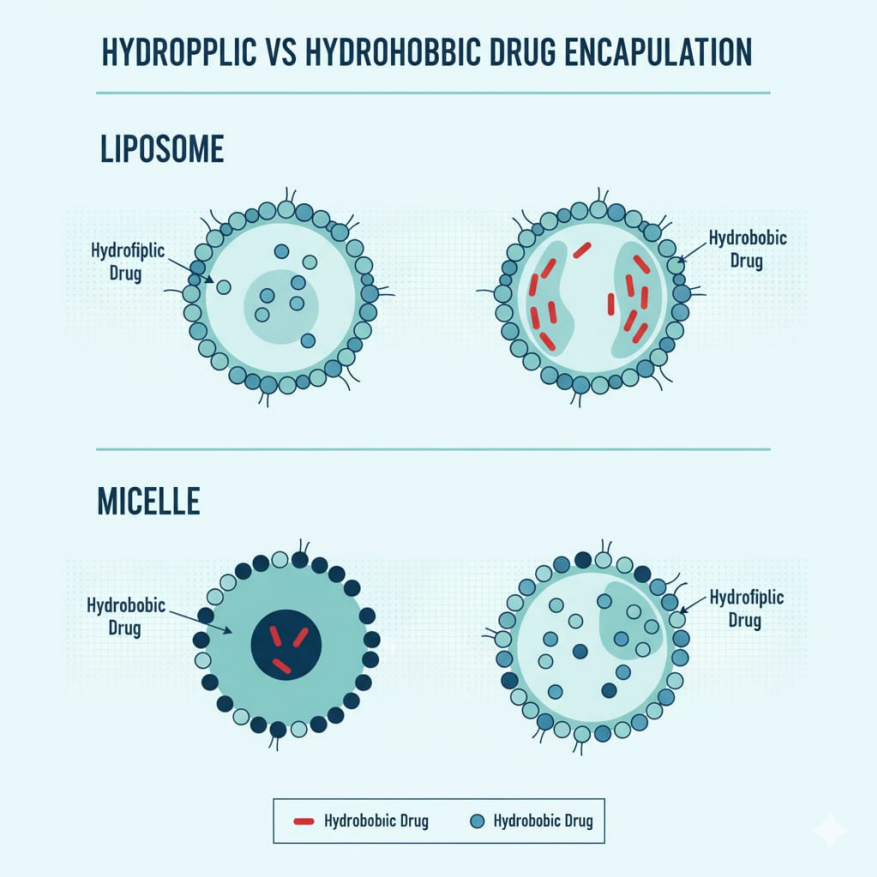

Figure 2: Mechanism Of Nanocarrier Drug Delivery.

genetic constituent against degradation as well authorizing secure and effective delivery to target cells (Cheng, 2012).

Vaccine Delivery

The Nanoparticles enhance immune response since they are used as adjuvants in the development of vaccines. They can carry antigens to immune cells, and result in improved immune response to the vaccine (Huang, 2010).

Protein and Peptide Drugs

Proteins and peptides are not stable in the body but nanomaterials are able to defend these biologics, enhancing it their bioavailability and stability. These can also be released under controlled and sustained release using nanoparticles medications. Figure 5 shows the applications of nanotechnology in medicines (Davis, 2016).

Challenges in Nanotechnology-Based Drug Delivery

Toxicity and Biocompatibility

Toxicity of nanoparticles is one of the greatest impediments to the development of nanomedicine. While many nanomaterials are not toxic to the body and their size is sometimes small enough to be deposited in the organs and tissues, which presents the risk of side effects. In this regard, extensive safety research would have to be carried out on regulatory approval (Kim, 2008; Frohlich, 2016).

Scalability and Manufacturing

Although the future of nanomaterials is bright, it is difficult to develop them on a large scale to manufacture and utilize them in large quantities continues to be problematic. Mainstream production must now be cost-effective or reproducible, whereas as well as was scalable to clinical demand (Roco, 2017).

Drug Release Control and Stability

The fact that drugs have to be controllable and the release has to be predictable is one of the biggest hindrances. Nanoparticles need to be designed to be stable enough to be used in physiological conditions, and also gives a released profile of consistent efficacy (Hallan, 2017).

Regulatory and Ethical Considerations

Nanomedicines are only approved by the regulatory authorities through rigorous testing in terms of safety and effectiveness. Ethical concerns regarding the risk of possible biological impacts or environmental damages barriers are also in subject scrutiny (Shahre, 2013).

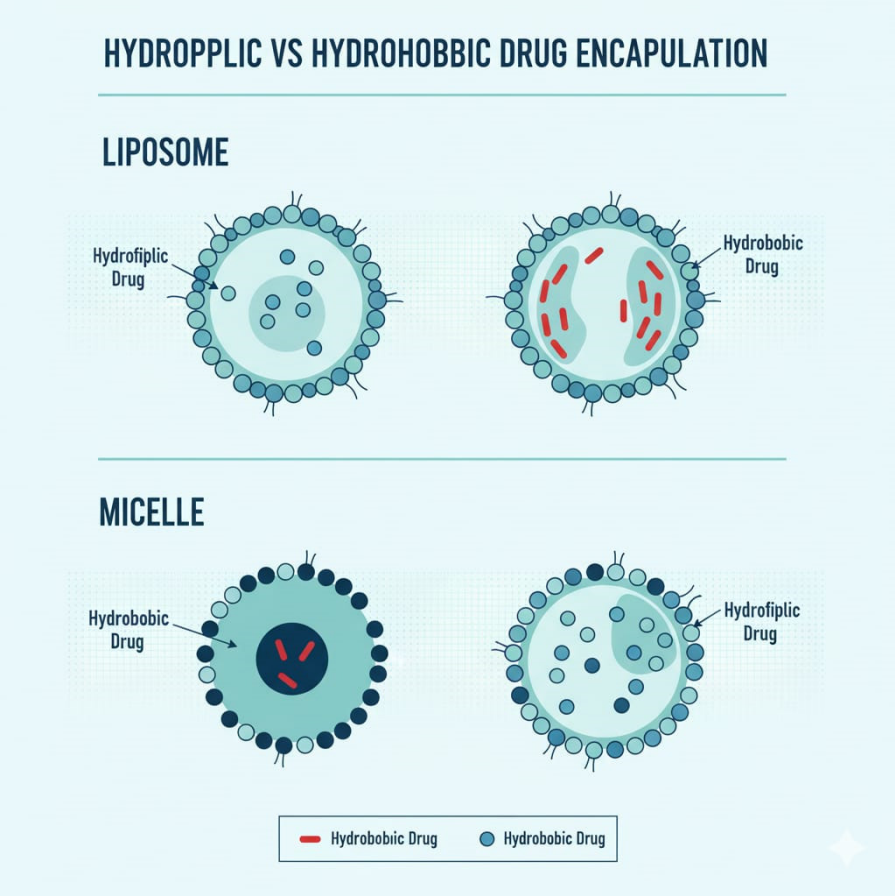

Figure 3: Hydrophilic Vs Hydrophobic Drug Encapsulation.

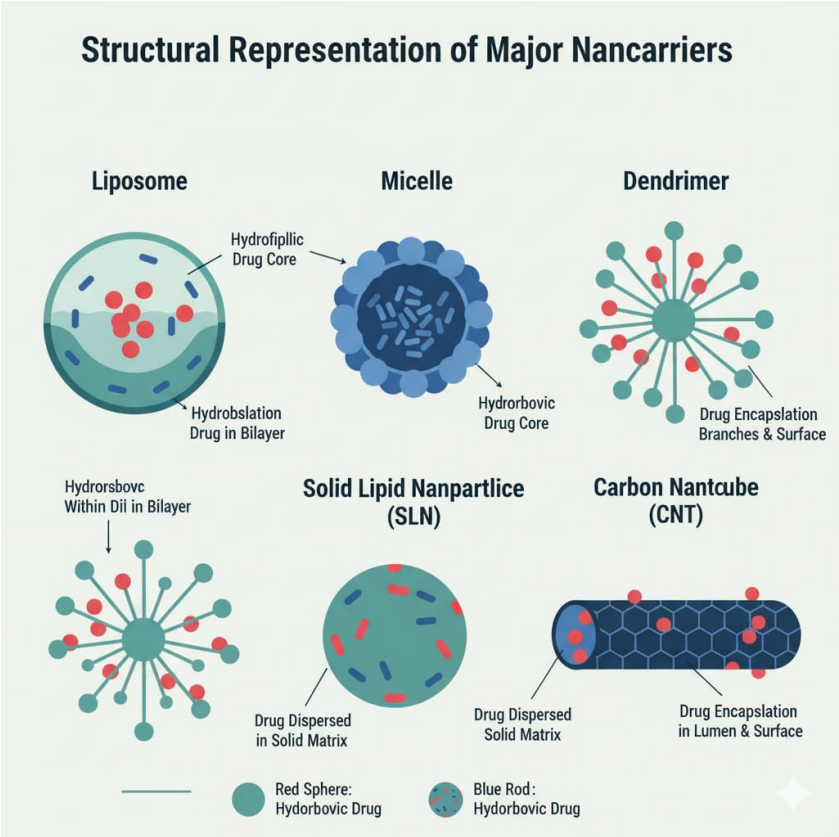

Figure 4: Structural Representation of Major Nanocarriers.

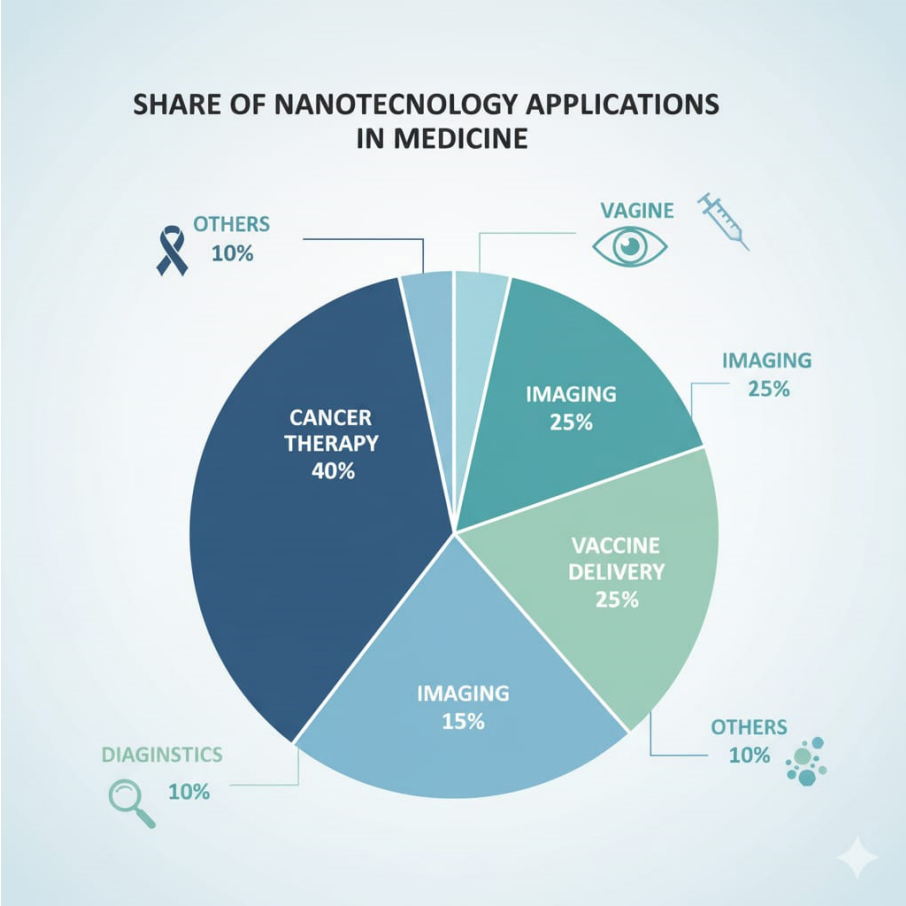

Figure 5: Application of Nanotechnology in Medicine.

FUTURE DIRECTIONS AND TRENDS

Emerging Nanomaterials

New nanoparticles are being developed which include nanogels, quantum dots and hybrid nanoparticles to carry drugs delivery. The purpose of these types of nanomaterials is to form superior targeting qualities, multifunctional compounds, and concomitant administration of a variety of treatments (e.g. chemotherapy and gene therapy) (Lu, 2021).

Personalized Medicine

In nanotechnology, one can develop tailor made drug delivery system which will be able to maximize treatment of individual patients according to genetic profiles, disease stage and therapy response (Nasrollahzadeh, 2019).

Artificial Intelligence in Nanomedicine

AI and machine learning are capable of designing better nanomedicines, predicting the behaviour of the drug delivery, and enhancing it design of improved therapeutic delivery (Roco, 2017).

CONCLUSION

Nanotechnology offers the transformational solutions regarding the drug delivery systems through increased precision, targeting, and efficacy. There are still difficulties of potential toxicity, scalability, and regulatory authorization. Even though, the future of nanomedicine is bright, active research is still going on to propel safer, better medication administration.

ABBREVIATIONS

DDS: Drug Delivery Systems; **EPR:** Enhanced Permeability and Retention; **SLNs:** Solid Lipid Nanoparticles; **CNTs:** Carbon Nanotubes; **DNA:** Deoxyribonucleic acid; **RNA:** Ribonucleic acid; **AI:** Artificial Intelligence.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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Cite this article: Ansaruddin N, Khalokar SS, Agrawal AD, Bele SS, Yadav SK, *et al*. Overview of Nanotechnology in Drug Delivery Systems. Life Sci Res Commn. 2026;2(1):1-6.