IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

Review on Advanced Drug Delivery System and Nanotechnology

Pradip A. Shelke[1], Sanjay K. Bais[2], Sakshi M. Pawar[3]
[1] Associate Professor, [2] Principal and Professor, [3] Student
Fabtech College of Pharmacy, Sangola
[3]sakshiapawar123@gmail.com

Abstract : *Nanotechnology enables the design and application of nanostructures to improve drug delivery by altering release, enhancing solubility, and increasing absorption of poorly water-soluble compounds APIs while reducing side effects. This Special Issue includes original research articles and reviews on novel nanocarriers that use environmentally friendly and sustainable synthesis methods, such as liposomes, metal and carbon nanoparticles, nanocrystals, and polymeric systems. Formulations techniques for encapsulating biological macromolecules are given particular attention, which advances the creation of effective, environmentally friendly delivery systems.*

Keywords: Drugs and Nanoparticles methods, Focused medication administration, Nanotechnology Based on nanoparticles formulations, regulated release and bioavailability improvement, Medicinal nanocarriers.

I. INTRODUCTION

Drug Delivery Systems (DDS) are specialized technologies developed to carry therapeutic agents throughout the body to produce the intended medical benefits. Their main objective is to regulate drug release so that medications reach the targeted site at the appropriate time and in the required dosage. DDS are an essential part of modern healthcare, as they improve treatment effectiveness, minimize unwanted side effects, and enhance patient adherence to medication [1]. Nanotechnology, a relatively new field of science, has gained considerable attention over the last twenty years and is rapidly advancing from laboratory-based research towards practical industrial applications.[2]

In pharmaceutical applications, nanotechnology offers promising solutions to the major drawbacks associated with conventional drug delivery systems. Traditional dosage forms, such as tablets and capsules, frequently encounter limitations such as low drug bioavailability, poor distribution to target tissues, and unwanted effects on healthy cells[3]. By manipulating materials at the nanoscale, advanced drug delivery systems can be developed to enhance therapeutic efficacy through regulated and sustained drug release, enhanced distribution, and site-specific drug delivery [4]. Nanoparticles can substantially improve the improving the pharmacological activity of drugs through increasing their stability and promoting site-specific delivery to designated targets sites in the body. Various types of nanoparticles, including polymeric, inorganic, and lipid-based nanoparticles, have demonstrated significant potential for use in advanced drug delivery systems.[5]

The Improvement of nanoparticles is an essential first step; however, a greater challenge lies in incorporating them into appropriate pharmaceutical dosage forms and subsequently evaluating the physicochemical and the biological characteristics of the final formulation. The present review seeks to offer an in-depth overview of nanoparticle-drug delivery approaches employing formulations.

II. OBJECTIVES

The objective of this review is to,

- Explore the historical progression of nanotechnology-based drug delivery systems and discuss the

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

fundamental principles underlying their development.

- Classify the different nanocarrier systems and discuss their key characteristics and structural features.
- Study the mechanisms that allow drugs to be delivered to specific sites and released in a controlled manner.
- Assess the medical uses and provide examples through real-world clinical case studies.
- Examine the existing challenges and explore possible future developments and advancements.

II. HISTORY AND DEVELOPMENT OF NANOTECHNOLOGY

1.Early progress in drug delivery technologies :

Traditional approaches to pharmaceutical formulation development was constrained by the inherent physicochemical properties of drugs. Several active pharmaceutical ingredients (APIs) demonstrated poor solubility or underwent rapid metabolism, resulting in reduced therapeutic efficacy [6]. Initial approaches primarily involved chemical alterations and traditional drug delivery methods carriers, which often lacked targeted delivery and exact control over drug release.

2 . Development of Nanotechnology-Based Approaches :

Developments in materials scientific advancements in the latter part of the period twentieth century played an important part in introducing nanotechnology into the area of drug administration[7]. Initial studies involving liposomes and polymer-based nanoparticles revealed that nanoscale drug formulations could enhance drug stability, improve biodistribution, and facilitate targeted drug delivery [8]. These advances have contributed to the emergence of personalized nanomedicine as a promising approach in modern pharmaceutical research.

III. THE BASIC NECESSITY AND TYPES OF NANOPARTICLES*

Due to their distinctive physicochemical characteristics, nanoparticles have gained considerable attention as promising drug delivery carriers for transporting various therapeutic agents to specific within the body. Such targeted Nano medicine systems can improve the therapeutic efficacy of drugs and enhance their biocompatibility, thereby increasing their overall therapeutic potential. Additionally, nanotechnology provides several benefits, enhancing the dissolution and bioavailability of drugs with low water solubility, shielding therapeutic agents from physiological barriers, supporting the development of innovative bioactive macromolecular drugs, and enabling the incorporation and delivery of higher drug concentrations.[9] Nanotechnology can be divided into two main categories: nanodevices and nanomaterials. Nanodevices comprise sophisticated systems such as respirocytes and nanoelectromechanical and microelectromechanical systems (NEMS/MEMS), which are developed for various biomedical applications. In contrast, nanomaterials are classified into nanostructured and nanocrystalline materials. Nanostructured materials are further divided into polymeric and non-polymeric nanocarriers. Polymeric nanocarriers include nanoparticles, dendrimers, micelles, and drug conjugates, which play an important role in targeted drug delivery and therapeutic applications. Non-polymeric nanomaterials include carbon nanotubes, metallic nanoparticles, silica nanoparticles, and quantum dots. These materials possess distinctive physicochemical characteristics that make them useful in diagnostic and therapeutic applications.[10]

IV. CLASSIFICATION OF NANO CARRIERS :

Nanocarriers are classified into different groups according to their composition, structural characteristics, and drug-loading mechanisms. Each type possesses distinct properties and benefits, making it suitable for various clinical application

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

1 – Liposomal Nanocarriers :

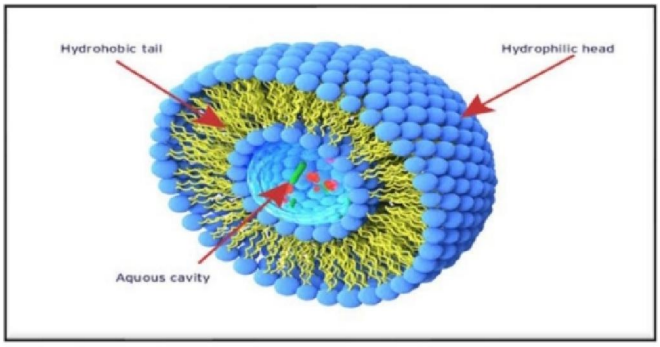


Figure 1. Schematic Representation of Non-Ionic Surfactant Vesicles (NSVs)

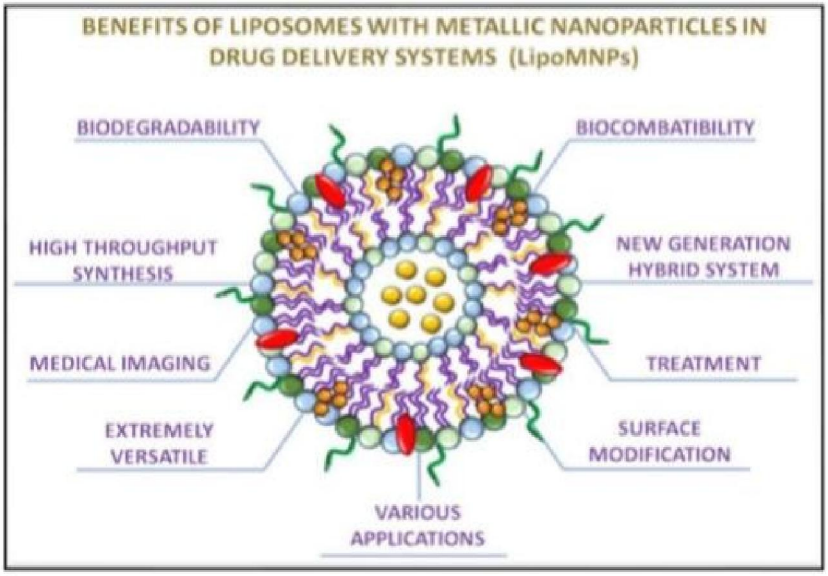


Figure 2. Advantages of Liposome–Metallic Nanoparticle Hybrid Systems for Drug Delivery (LipoMNPs)

Structure and Organisation :

Liposomes exhibit a spherical vesicular morphology structures made up consisting of one or multiple phospholipid double layers, which allow them to carry hydrophilic drugs within their aqueous interior and hydrophobic drugs within their lipid membrane[11].

V. ADVANTAGES AND PRACTICAL USES

Due to their excellent with their favourable biocompatibility and biodegradability, liposomes are extensively utilized as drug delivery carriers for anticancer drugs, immunization products and anti-infective compounds[11]. They possess the capacity to merge with cellular membranes facilitates the efficient transport of therapeutic agents into cells.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

2 -Polymeric Nanocarrires :

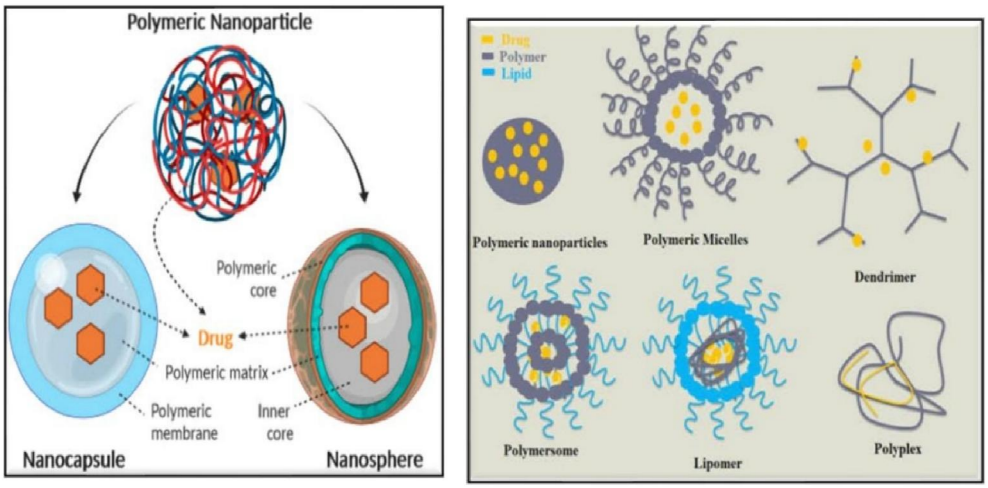


Figure 3 Illustrate various type of polymeric nanoparticles used in drug delivery system

VI. MATERIALS

These nanocarriers are commonly made from biodegradable polymers, such as poly(lactic-co-glycolic acid) (PLGA), to facilitate the controlled and prolonged release of drugs [12].

*Mechanisms and effect :

The adjustable decay characteristics and modifiable surface properties enable effective regulation drug elution patterns and targeted delivery, making these nanoparticles highly useful in cancer treatment, gene therapy, and the management of chronic diseases [12].

3- Dendritic nanocarriers :

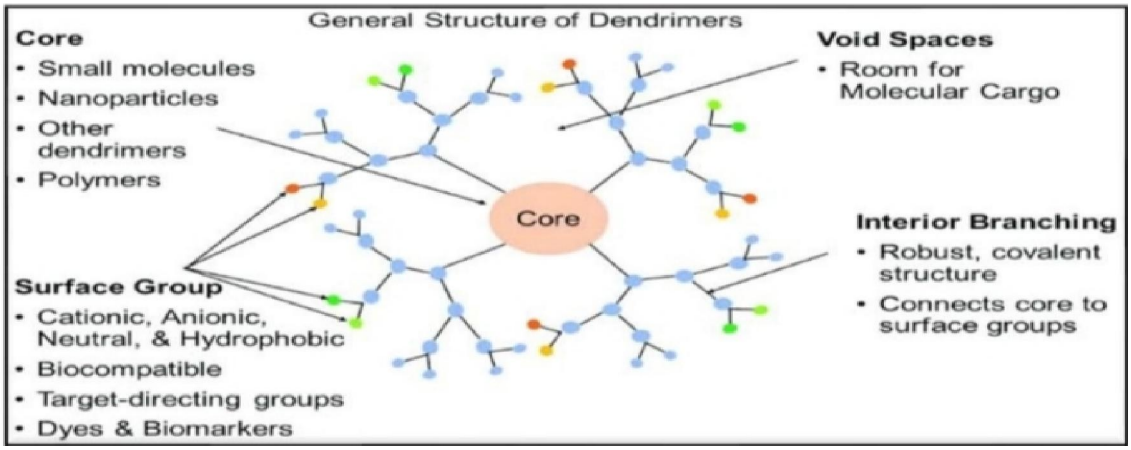


Figure 4. Schematic representation of the general structure of dendrimers

Dendrimers are structurally well-defined, highly branched macromolecules characterized by a tree-like architecture that develops from a central core. Their unique structure consists of numerous surface functional groups that can be chemically modified to fulfil particular therapeutic needs. The internal cavities of dendrimers facilitate drug encapsulation, while their outer surface allows the attachment of targeting molecules to enhance targeted drug delivery. Their precisely controllable size, shape, and surface characteristics make them promising carriers for various drug

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

delivery applications. Furthermore, their biodegradability and ability to accommodate high drug concentrations highlight their potential for delivering a wide range of therapeutic agents [13].

VII. ARCHITECTURE

Dendrimers are well-defined, highly branched macromolecules that possess a uniform and monodisperse molecular artitecture.The multiple terminal functional groups can be chemically modified to facilitate the attachment of therapeutic drugs, targeting molecules, and imaging agents[14] .

4. - Mi cellular Nano carriers :

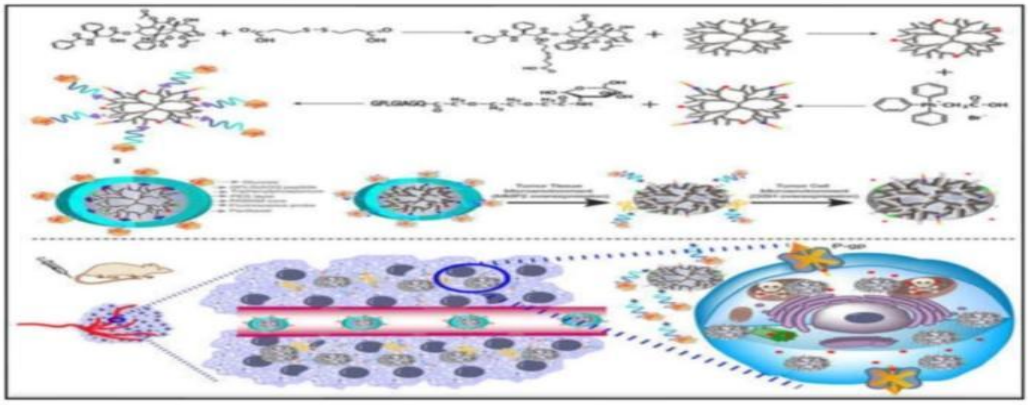


Figure 5 Schematic illustration of the glucose-PEG_peptide-triphenylphosphonium-PAMAM-PTX conjugate

Micelles are nanostructured drug carriers generated by the self-organization of amphiphilic molecules in aqueous media, typically ranging from 10 measuring up to 100 nm in diameter. They possess a distinctive structure containing a hydrophilic outer layer and a hydrophobic central core, which facilitates the incorporation of poorly water-soluble drugs. This arrangement improves active substance solubility enhances bioavailability. Given their versatile nature, micelles are widely used as delivery vehicles for various therapeutic and diagnostic agents, including pharmaceutical drugs, imaging agents, and diagnostic markers[15].

5 -Metallic Nanoparticles :

Metallic nanoparticles, especially gold and iron oxide nanoparticles, possess distinctive characteristics that make them promising candidates for drug delivery applications. Iron oxide nanoparticles generally consist of a magnetic core measuring approximately 4–5 nm, coated with hydrophilic polymers such as polyethylene glycol (PEG) or dextran. Their magnetic properties facilitating targeted therapeutic delivery while simultaneously making them useful in diagnostic imaging. In contrast, gold nanoparticles are known for their good biocompatibility and ease of surface modification, allowing them to be functionalized for specific targeting purposes [16].

6 -Quantum Dots :

Quantum dots are nanoscale fluorescent semiconductor particles with sizes typically ranging from 1 to 100 nm. Because of their unique optical characteristics, they have significant potential in biomedical applications, particularly in imaging and drug delivery. These nanocarrier systems can be specifically designed to transport therapeutic substances while also enabling real-time monitoring of their distribution under physiological conditions through their fluorescent signals [17].

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

Mechanisms Underlying Nanocarrier-Mediated Drug Delivery :

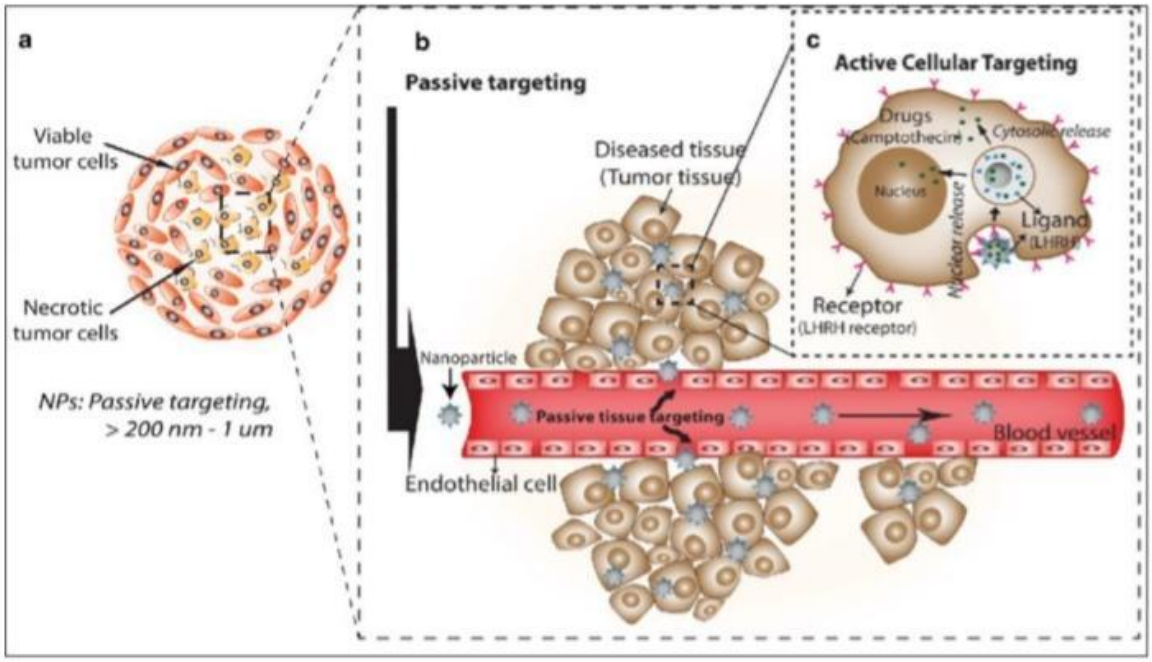


Figure 6 Nanocarrier-Assisted Drug Delivery

Nanocarriers improve the efficiency and accuracy of drug delivery by utilizing various mechanisms that facilitate targeted and controlled therapeutic administration.

(A)Targeted delivery -

(1) Passive targeting :

The Enhanced Vascular Permeability and Retention Phenomenon enables nanoparticles to preferentially accumulate in tissues with abnormal or highly permeable blood vessels, such as tumors and inflamed regions[18] . This passive accumulation reduces the necessity for additional active targeting approaches.

(2) Active Targeting :

Functionalizing nanoparticles with specific targeting ligands, such as antibodies or peptides, promotes receptor-mediated cellular uptake, enabling the selective delivery of drugs to facilitate selective cellular targeting [18]. This approach helps reduce unwanted potential adverse effects on non-target tissues while enhancing therapeutic efficacy.

VIII. APPLICATIONS

The incorporation of nanocarriers into drug delivery platforms has significantly advanced treatment strategies for various diseases. These carriers improve drug bioavailability, facilitate site-specific drug delivery, and allow controlled and sustained drug release[19].

1.Gastrointestinal Disorders :

Nanoparticle-mediated delivery platforms have exhibited considerable potential in the management of inflammatory bowel diseases (IBD). They facilitate targeted drug delivery to the colon, thereby minimizing systemic drug exposure and improving treatment effectiveness. Additionally, nanocarriers shield therapeutic agents from degradation within the harsh gastrointestinal environment and promote their localized release at inflamed sites [20].

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

2. Bone Regeneration :

Nanostructured materials have significantly advanced the field of bone tissue engineering. Hydrogel-based nanocomposites and nanocrystalline hydroxyapatite exhibit excellent potential for promoting bone regeneration. Furthermore, self-assembled rosette nanotubes, formed through the chemical arrangement of DNA base pairs, replicate the native nanoscale architecture of bone tissue, thereby improving tissue integration and facilitating the healing process [21].

3. Retinal Disorders :

Nanocarrier-mediated drug delivery approaches have helped overcome several challenges associated with the treatment of posterior segment eye diseases, especially the necessity of repeated intravitreal injections. Advanced formulations, such as liposomes, nanospheres, and nanoemulsions, enable prolonged drug release and improve drug transport across ocular barriers. These systems help sustain therapeutic drug levels in ocular tissues while minimizing the frequency of treatment procedures. In particular, cyclodextrin-based nanoparticle have demonstrated encouraging potential for site-specific delivery of poorly water-soluble drugs to retinal tissues [22].

4. Management of Diabetes :

Nanotechnology has opened up new possibilities for diabetes management by employing various therapeutic strategies. Nanopore-based devices can shield transplanted pancreatic beta cells from immune system attacks while preserving their insulin-secreting function. Biodegradable nanospheres facilitate the gradual and regulated delivery of insulin, whereas advanced nanorobotic systems present opportunities for monitor blood glucose levels and respond to fluctuations. Additionally, polymer-based nanocarriers have improved the prospects of oral insulin administration by protecting insulin from enzymatic breakdown and enhancing its intestinal absorption [23].

5. Tuberculosis Treatment :

Nanotechnology-based approaches to tuberculosis (TB) treatment encompass both therapeutic and preventive strategies. Liposomal and lipid nanoparticle formulations have significantly improved the delivery of anti-TB medications. These systems achieve sustained drug release profiles and enhanced pharmacokinetic properties, potentially reducing dosing frequency and improving patient compliance. The nanocarriers reduce the breakdown of pharmaceutical compounds and enable selective delivery to infected tissues [24].

6. Dental Applications :

The application of nanotechnology in dentistry has facilitated the development of accurate and minimally invasive treatment approaches. Nanorobotic dentifrices, incorporated into toothpaste or mouthwash, may help monitor and maintain oral hygiene by continuously eliminating calculus deposits and organic residues. These microscopic systems are designed to break down accumulated debris into harmless vapours. In orthodontics, nanorobots have the capability to manipulate periodontal tissues with high precision, allowing controlled tooth movement while minimizing patient discomfort[25].

IX. ADVANTAGES AND DISADVANTAGES

1.Advantages :

Nanotechnology-based drug delivery systems provide several advantages by overcoming many of the limitations associated with conventional drug delivery methods. They enhance drug bioavailability by improving solubility and membrane permeability, thereby increasing therapeutic efficacy. Their ability to deliver drugs selectively to specific target sites minimizes exposure to healthy tissues and reduces the risk of adverse effects. Furthermore, controlled and sustained drug release maintains consistent and effective medication levels in the body for prolonged periods, minimizing the rate of administration and improving patient compliance with treatment [26].

In addition, nanocarrier-based systems facilitate the release of sensitive therapeutic molecules, such as proteins, peptides, and nucleic acids, which are often susceptible to degradation through conventional delivery routes. Their flexible structure also allows the incorporation of multiple therapeutic agents, supporting combination therapy.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 4, November 2026 Impact Factor: 8.2

Moreover, certain nanocarriers possess imaging capabilities that enable real-time monitoring of drug distribution and evaluation of therapeutic responses[27].

2 .Limitations :

Although nanotechnology-based drug delivery systems offer numerous benefits, several limitations and challenges remain in their development and practical application.

Manufacturing Challenges :

Large-scale manufacturing of nanotechnology-based drug delivery systems remains challenging, especially in ensuring uniformity in particle size and surface characteristics. Additionally, the complicated production procedures can increase manufacturing expenses, which may restrict their cost-effectiveness and commercial application [28].

Biological Barriers :

Although nanocarriers are capable of overcoming several biological barriers, achieving uniform penetration into tissues and efficient cellular internalization remains a major challenge. Furthermore, the removal of nanoparticles by the reticuloendothelial system may decrease their therapeutic effectiveness, highlighting the need for appropriate surface modifications to improve their circulation time and delivery efficiency [29].



X. CONCLUSION

Nanotechnology-based drug delivery systems have emerged as a significant advancement in pharmaceutical science, providing innovative approaches to overcome several traditional challenges in drug therapy. The development of different nanocarriers and their sophisticated delivery mechanisms has improved the effectiveness, accuracy, and targeted administration of therapeutic agents for various diseases. Despite certain limitations related to large-scale production, biological barriers, and regulatory requirements, continuous research and technological progress are helping to overcome these obstacles. The future of nanomedicine focuses on designing advanced multifunctional delivery systems capable of combining different therapeutic agents, achieving precise targeting, and ensuring controlled drug release. Furthermore, the integration of artificial intelligence and personalized medicine is expected to accelerate the development of nanotechnology-based therapies, expanding their potential in the treatment of complex medical conditions.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

REFERENCES

1. Panyam J, Labhasetwar V. Biodegradable nanoparticles for drug and gene delivery to cells and tissue. Adv Drug Devil Rev. 2003;55(3):329-47.
2. Nasrollahzadeh M, Sajadi SM, Sajjadi M, Issaabadi Z. An Introduction to Nanotechnology. In: Interface Science and Technology. Vol 28. Elsevier; 2019:1-27. doi:10.1016/B978-0-12-813586-0.00001-8.
3. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. ACS Nano. 2009;3(1):16-20.
4. Duncan R, Gaspar R. Nanomedicine(s) under the microscope. Molecular Pharmaceutics. 2011;8(6):2101-41.
5. Beach MA, Nayanathara U, Gao Y, et al. Polymeric Nanoparticles for Drug Delivery. Chem Rev. 2024;124(9):5505-5616. doi:10.1021/acs.chemrev.3c00705.
6. Duncan, R. (2003). "The Dawning Era of Polymer Therapeutics" Nature Reviews Drug Discovery, 2(5), 347–360.
7. (Mitragotri, S., Burke, P. A., & Langer, R. (2014). "Overcoming the Challenges in Administering Biopharmaceuticals: Formulation and Delivery Strategies" Nature Reviews Drug Discovery, 13(9), 655–672
8. Peer, D., Karp, J. M., Hong, S., FaroKhzad, O. C., Margalit, R., & Langer, R. (2007). "Nanocarriers as an Emerging Platform for Cancer Therapy" Nature Nanotechnology, 2(12), 751–760.
9. Yusuf A, Almotairy ARZ, Henidi H, Alshehri OY, Aldughaim MS. Nanoparticles as Drug Delivery Systems: A Review of the Implication of Nanoparticles' Physicochemical Properties on Responses in Biological Systems. Polymers. 2023;15(7):1596. doi:10.3390/polym15071596.
10. Annabelle Hett. Nanotechnology: Small Matter Many Unknowns.; 2004.
11. Immordino, M. L., Dosio, F., & Cattel, L. (2006). "Stealth Liposomes: Review of the Basic Science, Rationale, and Clinical Applications, Existing and Potential" International Journal of Nanomedicine, 1(3), 297–315.
12. Fessi, H., Puisieux, F., Devissaguet, J. P., Ammoury, N., & Benita, S. (1989). "Nanocapsule Formation by Interfacial Polymer Deposition Following Solvent Displacement" International Journal of Pharmaceutics, 55(1), R1–R4.
13. Svenson S, Tomalia DA. Dendrimers in biomedical applications—reflections on the field. Advanced Drug Delivery Reviews. 2005;57(15):2106-29.
14. Gillies, E. R., & Fréchet, J. M. (2005). "Dendrimers and Dendritic Polymers in Drug Delivery" Drug Discovery Today, 10(1), 35–43.
15. Kataoka K, Harada A, Nagasaki Y. Block copolymer micelles for drug delivery: design, characterization and biological significance. Advanced Drug Delivery Reviews. 2001;47(1):113-31.
16. Boisselier E, Astruc D. Gold nanoparticles in nanomedicine: preparations, imaging, diagnostics, therapies and toxicity. Chemical Society Reviews. 2009;38(6):1759-82.
17. Medintz IL, Uyeda HT, Goldman ER, Mattoussi H. Quantum dot bioconjugates for imaging, labelling and sensing. Nature Materials. 2005;4(6):435-46
18. Maeda, H., Wu, J., Sawa, T., Matsumura, Y., & Hori, K. (2000). "Tumor Vascular Permeability and the EPR Effect in Macromolecular Therapeutics: A Review" Journal of Controlled Release, 65(1–2), 271–284.
19. Wang AZ, Langer R, Farokhzad OC. Nanoparticle delivery of cancer drugs. Annual Review of Medicine. 2012;63:185-98.
20. Beloqui A, Coco R, Préat V. Targeting inflammatory bowel diseases by nanocarriers loaded with small and biologic drugs. Current Pharmaceutical Design. 2016;22(19):2872-82.
21. Stevens MM, George JH. Exploring and engineering the cell surface interface. Science. 2005;310(5751):1135-8.
22. Kompella UB, Amrite AC, Pacha Ravi R, Durazo SA. Nanomedicines for back of the eye drug delivery, gene delivery, and imaging. Progress in Retinal and Eye Research. 2013;36:172-98.
23. Pickup JC, Zhi ZL, Khan F, Saxl T, Birch DJ. Nanomedicine and its potential in diabetes research and

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

practice. Diabetes/Metabolism Research and Reviews. 2008;24(8):604-10

24. Gelperina S, Kisich K, Iseman MD, Heifets L. The potential advantages of nanoparticle drug delivery systems in chemotherapy of tuberculosis. American Journal of Respiratory and Critical Care Medicine. 2005;172(12):1487-90.
25. 25 Curtis AR, Wilkinson CD, Crossan A, Broadley C, Dallaire H, Bartzoka V, et al. Cell adhesion and proliferation on nanopatterned surfaces. IEEE Transactions on Nanobioscience. 2004;3(1):61-5.
26. Kamaly N, Xiao Z, Valencia PM, Radovic-Moreno AF, Farokhzad OC. Targeted polymeric therapeutic nanoparticles: design, development and clinical translation. Chemical Society Reviews. 2012;41(7):2971-3010.
27. Mitragotri S, Burke PA, Langer R. Overcoming the challenges in administering biopharmaceuticals: formulation and delivery strategies. Nature Reviews Drug Discovery. 2014;13(9):655-72.
28. Desai N. Challenges in development of nanoparticle-based therapeutics. The AAPS Journal. 2012;14(2):282-95.
29. Blanco E, Shen H, Ferrari M. Principles of nanoparticle design for overcoming biological barriers to drug delivery. Nature Biotechnology. 2015;33(9):941-51.