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NANO CARRIERS IN DRUG DELIVERY: A COMPREHENSIVE OVERVIEW OF ADVANCES AND APPLICATIONS

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ABSTRACT

The fact that nanocarriers emerged as a revolutionary tool in drug delivery has significantly improved drug bioavailability, stability, and therapeutic efficacy of pharmaceutical agents. Based on the nanoscale delivery systems such as liposomes, dendrimers, nanoparticles and micelles, the targeted and controlled drug release has been achieved to improve drug accumulation at the site of action and to reduce the systemic side effect. Nanocarriers make them versatile in being able to carry a large range of therapeutic agents from chemotherapeutic drugs to proteins, peptides and nucleic acids with improved but fewer toxic characteristics. However, the challenges of biocompatibility, scalability, regulatory approval and safety in the long term still have to be solved. This review presents a general overview of the recent attempt in developing drug delivery systems based nanocarrier that covers the different types of nanocarriers, the applications in different therapeutic areas with the strategies of overcoming the present limitations. Secondly, the article highlights future directions of nanocarriers, including integrated personalized medicine, multifunctional nanocarriers, advanced technologies such as artificial intelligence of nanocarrier design. Nanocarriers, in general, represent an exciting frontier in drug delivery, and the ability to use them in the treatment of a large variety of diseases that includes cancer, infectious diseases and neurological disorders.

KEYWORDS: Nanocarriers, drug delivery, liposomes, dendrimers, targeted drug release, biocompatibility, personalized medicine.

1. INTRODUCTION

The problem of targeted delivery of therapeutic agents to specific sites within the body, has been one of the most important problems in contemporary pharmacotherapy.[1] However, diverse and diverse problems, such as poor bioavailability, lack of target specificity, short systemic circulation, and undesired side effects, make conventional drug delivery systems unsuitable in many situations.[2] For instance, these problems are particularly significant in the therapy of complex diseases such as cancer, neurological disorders, and infectious diseases where the therapeutic window is narrow, the drug exposures in non-target tissues can be high, and favorable drug absorption, distribution and metabolism are subjacent to successful therapy.[3] In order to overcome these limitations, the field of drug delivery is shifting towards the nanotechnology-based approaches. Nanocarriers have been especially attracting much attention as novel tools for increasing the therapeutic efficacy and safety of drugs among these.[4] Colloidal drug delivery system are nanocarriers that have particle size between 1 to 1000 nanometres. A suite of advantages, which are improved solubility of poorly water-soluble drugs, prolonged circulation time, controlled and sustained release, targeted drug delivery and reduced systemic toxicity, are offered by them. As can be seen, these characteristics play an important role in determining the improved patient compliance and clinical outcomes.[5] Nanocarriers exhibit unique physicochemical properties of surface modifiability and high surface area to volume ratio, and high encapsulation capacity of hydrophilic and hydrophobic drug, which make them appropriate for many therapeutic applications. And they can be designed with a range of polymers, lipids, metals, and surfactants so that it can be tuned to disease pathology, pharmacokinetics, and drug properties. The targeting ligands are also used for functionalizing nanocarriers; antibodies, peptides or aptamers can be employed for achieving the site-specific delivery, for instance, in cancer and inflammatory diseases where receptor mediated endocytosis can be utilized for enhanced cellular uptake. With recent advances in nanomedicine and the development of stimuli responsive nanocarriers that release their payload in response to physiological or external trigger such as pH, temperature, enzymes, or light, much thousands stand to be gained on the ability to develop new types and qualitative application of this local nanomedical intervention.[6] Moreover, nanocarrier integration of diagnostic agents into theragnostic has led to platforms for simultaneous diagnosis and therapy, particularly in

personalized medicine, due to the synchronous therapy and diagnosis. On the face of it, nanocarrier based drug delivery systems to the clinic are promising, but there are several challenges that have not been overcome. Systematic solution is needed to issues of large-scale manufacturing, reproducibility, long term toxicity, regulatory approval and cost effectiveness. In addition, it is necessary to understand better their interaction with biological systems, such as the formation of protein corona, recognition by the immune system, and biodistribution for successful clinical implementation.[7]

2. Fundamentals of Nanocarriers

Nanocarriers are nanoscale structures for the specific delivery of therapeutic agents to the targeted tissue or a targeted cell with increased precision, effectiveness and safety. Most of these carriers have sizes ranging from 1 to 1000 nanometers and are composed of many different materials, such as polymers, lipids, surfactants, and inorganic substances. Factors that are critical to design and physicochemical aspects, including drug loading efficiency, stability, and release kinetics and biodistribution are dependent on theirs.[8] Nanocarriers are Nano sized materials such as Nano drugs that are meant to be used in controlled and targeted delivery of the drugs. Table 1 gives Characteristics of Nanocarriers in Drug Delivery, However, because of their small size, their permeability and retention are increased (EPR) even in diseased tissues, such as tumours, characteristics of nanocarriers include.

- High surface area-to-volume ratio
- Tunable surface charge and hydrophilicity/hydrophobicity
- Ability to encapsulate both hydrophilic and hydrophobic drugs
- Protection of the drug from enzymatic degradation

2.1 Mechanism of Drug Loading and Release

Physical entrapment, chemical conjugation and surface adsorption are known methods of drug loading into nanocarriers. Passive diffusion, degradation of the carrier matrix or stimuli sponge mechanisms (e.g. targeting of changes in pH, temperature, enzymatic activity) may be the driving forces for the release or passage of the drug from the nanocarriers. The controlled release products significantly contribute to maintaining therapeutic drug levels over an extended period and decreasing the frequency of dosing.[9]

2.2 Targeting Strategies

Passive Targeting takes advantage of nanocarriers' naturally accumulated into diseased tissues (e.g., tumor or inflamed) by the effect of EPR and Active Targeting is done by modifying nanocarrier surface with ligands like monoclonal antibodies, peptides, or folic acid that recognized targets that over expressed the specific receptors.[10]

2.3 Surface Modification and Functionalization

Nanocarriers can be PEGylated that is coated with a polymer such as polyethylene glycol (PEG) to increase circulation time and decrease immunogenicity.[11] Other modifications include.

- pH-sensitive linkers for site-specific release
- Ligand conjugation for receptor-mediated uptake
- Guided delivery and imaging with magnetic or optical elements

2.4 Pharmacokinetic and Pharmacodynamic Improvements

Nanocarriers increase solubility, decrease metabolism and prolong half-life of drugs by an order of magnitude. Targeted delivery also can improve pharmacodynamic outcomes by drug localization at disease site and limiting drug effect on healthy tissues.[12]

Table 1: Characteristics of Nanocarriers in Drug Delivery.

Parameter	Description	Impact on Drug Delivery	Reference
Size (1–1000 nm)	Nano-range particle size improves tissue penetration and cellular uptake	Enhances bioavailability and allows for passive targeting (EPR effect)	[13]
Surface Charge (Zeta Potential)	Affects stability, cellular interaction, and circulation time	Positive charge enhances cell uptake; neutral/PEGylated prolongs circulation	[14]
Drug Loading Methods	Encapsulation, adsorption, conjugation	Determines drug payload and release profile	[15]
Release Mechanism	Diffusion, erosion, stimuli-responsive (pH, temperature, enzymes)	Enables controlled and site-specific drug release	[16]
Biodegradability	Use of polymers or lipids that degrade into non-toxic components	Ensures safety and minimizes long-term accumulation	[17]
Targeting Strategy	Passive (EPR effect), active (ligand-mediated)	Improves therapeutic index and reduces off-target effects	[18]
Surface Modification	PEGylation, ligand conjugation, magnetic tagging	Enhances stealth properties and target specificity	[19]
Drug Compatibility	Suitable for both hydrophilic and hydrophobic drugs	Expands applicability to a wide range of therapeutic agents	[20]

3. Types of Nanocarriers

In the past decades some nanocarrier systems have been developed to overcome the pitfalls relevant to conventional drug delivery. Each type of nanocarrier exhibits unique structural features, advantages, limitations, and suitability for different therapeutic applications.[21]

3.1 Polymeric Nanoparticles

These colloidal particles made from biodegradable polymers are named polymeric nanoparticles: polylactic acid (PLA), polyglycolic acid (PGA), poly(lactic-co-glycolic acid) (PLGA), and chitosan. They have good stabilities, controlled release properties and are capable to contain hydrophobic and hydrophilic drugs. Advantages: Biocompatibility, tunable degradation rate, easy surface modification. Applications: Cancer therapy, vaccine delivery, antimicrobial agents.[22]

3.2 Liposomes

Spherical vesicles composed of one or more phospholipid bilayers enclosing an aqueous core is a definition of liposomes. Both water-soluble and lipid soluble drugs can be encapsulated by them and are among the first and most common approved nanocarrier systems. Advantages: Biodegradable, low toxicity, well-studied, FDA-approved products available and Applications: Oncology (e.g., Doxil®), antifungal drugs (e.g., AmBisome®), gene therapy.

3.3 Solid Lipid Nanoparticles (SLNs)

They can be defined as submicron size particles of solid lipids that remain solid both at room and body temperature. The real strength of these nanoparticles is that they combine the excellent benefits of lipid carriers and polymeric nanoparticles at the same time. Improved drug stability, controlled release, good biocompatibility; Advantages of the applications in dermatological, ophthalmic, and oral drug delivery.[23]

3.4 Nanostructured Lipid Carriers (NLCs)

Second generation of lipid nanoparticles are NLCs, wherein lipids are mixture of solid & liquid lipids. Comparing to SLNs, higher drug loading and reducing expulsion during storage are achieved in them. Advantages: Increased loading capacity, reduced crystallinity, improved stability and Applicati*ons: Transdermal delivery, antiaging formulations, anti-inflammatory* drugs.

3.5 Dendrimers

These are highly branched tree like synthetic macromolecules having a central core with multiple terminal functional group. As their architecture is well defined, drugs can precisely be loaded and targeted.[24]

- Advantages: Multivalency, uniform size, potential for gene and drug delivery
- Applications: Antiviral agents, anticancer therapy, diagnostic imaging

3.6 Nanosuspensions

Pure drug particle nanosuspensions are relatively low concentration submicron colloidal dispersions of pure particles stabilized by surfactants. It is suitable for poorly soluble drugs to improve the dissolution and absorption.

- Advantage: Easy to prepare, soluble increased, scalable production
- Applications: Oral, parenteral, and ocular drug delivery

3.7 Metallic and Inorganic Nanocarriers

Gold nanoparticles, silver nanoparticles, mesoporous silica and quantum dots are a part of these. As a result, they are often used to image, diagnose, and target delivery as a consequence of their unique optical and magnetic properties.[25]

Advantages: Surface plasmon resonance, ease of functionalization, diagnostic potential.

Applications: Theranostics, cancer photothermal therapy, biosensing.

Table 2: Comparative Overview of Common Nanocarriers.[26, 27]

Nanocarrier Type	Composition	Drug Type Compatibility	Clinical Use
Polymeric Nanoparticles	PLA, PLGA, Chitosan	Hydrophilic/Hydrophobic	Cancer, vaccines
Liposomes	Phospholipids	Both	Oncology, gene delivery
Solid Lipid Nanoparticles	Solid lipids	Lipophilic mainly	Dermatology, eye diseases
NLCs	Solid + liquid lipids	Lipophilic mainly	Topical, systemic
Dendrimers	Polyamidoamine (PAMAM)	Hydrophilic/Hydrophobic	Anticancer, imaging
Nanosuspensions	Drug + surfactant	Poorly soluble drugs	Oral/parenteral/ocular
Metallic/Inorganic NPs	Gold, silica, quantum dots	Variable	Theranostics, diagnostics

4. Recent Advances and Innovations in Nanocarriers

Recent developments in nanocarrier systems have revolutionized drug delivery by introducing intelligent, multifunctional, and patient-specific platforms. Among these, stimuli-responsive nanocarriers have gained prominence for their ability to release drugs in response to pH, redox potential, temperature, enzymes, or external stimuli like light and magnetic fields, enabling precise targeting and reduced systemic toxicity.[28] Multifunctional and hybrid nanocarriers integrate therapeutic and diagnostic functionalities, forming "theranostic" systems capable of simultaneous treatment and monitoring. Additionally, co-delivery nanocarriers allow the simultaneous transport of drugs and genetic material (e.g., siRNA, CRISPR/Cas9), enhancing efficacy in complex diseases like cancer and genetic disorders.[29] Targeted nanomedicine is now increasingly guided by personalized approaches, using ligand-modified surfaces to deliver drugs based on specific biomarkers or disease profiles. The delivery of gene-editing tools via non-viral nanocarriers, such as lipid nanoparticles (LNPs), has emerged as a breakthrough in safe and efficient gene therapy. Furthermore, environmentally friendly and biogenic nanocarriers synthesized using plant-based or microbial components are being developed for sustainable and low-toxicity applications.[30] A comparison of these innovations is presented in **Table 3**, highlighting their mechanisms, advantages, and potential applications.

Table 3: Recent Innovations in Nanocarriers.[31, 32, 33]

Innovation Type	Trigger/Feature	Advantage	Applications
Stimuli-Responsive	pH, redox, enzymes, temperature, magnetic	Site-specific release, reduced side effects	Cancer, inflammation
Multifunctional/Hybrid	Imaging + therapy, magnetic/lipid hybrid	Theranostics, enhanced targeting	Tumor imaging, real-time monitoring
Dual/Co-delivery	Drug-drug or drug gene combos	Synergistic effect, reduced resistance	Cancer, antimicrobial resistance
Personalized Nanomedicine	Ligand-based targeting, AI-guided design	Precision delivery, tailored therapy	Oncology, metabolic disorders
CRISPR/Gene Delivery	mRNA, siRNA, Cas9 via lipid/polymer carriers	Non-viral, safe gene editing	Genetic diseases, personalized therapy
Biogenic/Green Nanocarriers	Plant or microbial synthesis	Eco-friendly, minimal toxicity	Antimicrobials, topical delivery

5. Applications of Nanocarriers in Drug Delivery

5.1 Cancer Therapy

There are many advantages that cancer treatments have derived from nanocarrier use; especially in the improvement of chemotherapeutic delivery to tumour areas. Nanocarriers have the opportunity to use this enhanced permeability and retention (EPR) effect that are characteristic of tumor tissues, in which the blood vessels are more permeable and lymphatic drainage is poor.[34]

- **Liposomes** (e.g., Doxil®) are widely used for encapsulating chemotherapeutics like doxorubicin, reducing cardiac toxicity.
- **Polymeric nanoparticles** can provide sustained release of drugs, reducing the frequency of administration and improving patient compliance.
- **Nanoparticles conjugated with targeting ligands** (e.g., monoclonal antibodies, folate) enhance specificity, thus improving the therapeutic index.

5.2 Infectious Diseases

Nanocarriers have been used as efficient solubilizing and stabilizing agents as well as effective delivery systems for antibiotics and antifungals for treating infectious diseases. They also help in the delivery of therapeutic agents to areas that can only be accessed with considerable difficulty as a result of tissue restrictions.[35]

- **Nanosuspensions** and **lipid-based carriers** are used for poorly soluble antibiotics, improving their bioavailability.
- **Gold nanoparticles** and **silver nanoparticles** are increasingly being used for their antimicrobial properties, providing an alternative for antibiotic-resistant infections.
- **Nano-antibiotics** encapsulated in nanocarriers offer sustained drug release, reducing the risk of resistance development and side effects.

5.3 Gene Delivery

The use of genetic therapy as a possible treatment for genetic diseases is quite promising, but the problem of introducing genetic material into the target cell still persists. Lipid based nanoparticles, in general and specifically the ones commonly called lipid nanoparticles, are promising non-viral gene delivery systems.[36]

- **Lipid nanoparticles** were the key component in the success of mRNA vaccines for COVID-19.

- **Polymeric nanoparticles** can deliver DNA, RNA, or CRISPR/Cas9 components for gene editing, with potential applications in treating genetic disorders such as cystic fibrosis and muscular dystrophy.
- **Dendrimers** and **viral-like particles** can be used for both gene delivery and gene silencing, offering precision targeting.

5.4 Vaccine Delivery

Nanocarriers have also been explored for improving vaccine formulations by enhancing the immune response and providing controlled release of antigens.[37]

- **Liposomes** and **microparticles** are employed as adjuvants to enhance the efficacy of vaccines.
- **Nanoparticles** (e.g., gold or silica) can deliver antigens in a manner that mimics natural pathogens, boosting both humoral and cellular immunity.

5.5 Neurological Disorders

Highly potential nano carriers have been regarded as important strategies for the treatment of central nervous system diseases including Alzheimer's disease, Parkinson's disease, and stroke. The introduction of drugs across the BBB remains one of the limiting factors in drug administration to the brain; nanocarriers may be a solution.[38]

- **Liposomes** and **solid lipid nanoparticles (SLNs)** are designed to cross the BBB and deliver neuroprotective drugs or gene therapy agents.
- **Nanoparticles conjugated with targeting ligands** (e.g., transferrin or lactoferrin) can improve brain targeting, enhancing the therapeutic potential for neurodegenerative diseases.

Table 4: Applications of Nanocarriers in Disease Management.[39, 40]

Disease Area	Nanocarrier Type	Therapeutic Benefits	Examples
Cancer Therapy	Liposomes, Polymeric Nanoparticles	Targeted drug delivery, reduced side effects	Doxil® (Doxorubicin), Nanoparticle-based systems
Infectious Diseases	Nanosuspensions, Lipid Carriers	Enhanced drug bioavailability, antimicrobial effects	Gold NPs, Silver NPs, Nano-antibiotics
Gene Delivery	Lipid Nanoparticles, Dendrimers	Non-viral gene delivery, gene editing	CRISPR, mRNA vaccines
Vaccine Delivery	Liposomes, Nanoparticles	Enhanced immune response, controlled release	Nano-adjuvants, Antigen-loaded Liposomes

Neurological Disorders	Liposomes, SLNs, Dendrimers	BBB crossing, targeted drug delivery	Drug-loaded SLNs for Alzheimer's, Parkinson's

6. Challenges and Future Directions

Despite the enormous potential of nanocarriers, various challenges remain that prevent their clinic wide application. The toxicity and the biocompatibility of nanomaterials have been considered one of the primary concerns as the prolong exposure of nanoparticles may cause them with adverse effects, especially in sensitive organs.[41] The major barrier to the scalability of nanocarrier production remains the loss of reproducibility and uniformity of the reaction, which that are not tolerated for use in clinical settings.[42] There are also regulatory hurdles because nanomedicines often are complex to approve due to the inherent technological complexity, and long term effects of nanocarrier compounds on human health are not fully understood. Additionally, efficient targeting and charged drug release in a controlled fashion is not easily attained due to unpredictability of the interaction of nanocarriers with biological barriers, including the blood brain barrier, the immune system, and so on. In terms of future directions, personalized nanomedicine and smart nanocarriers responsive toward individual biomarkers are promising in improving therapeutic outcome.[43] Thus, multifunctional platforms integrating therapeutic, diagnostic, and in some cases, also drug delivery modalities (theranostics), are expected to perform simultaneously disease monitoring and treatment. In addition, the study of biodegradable, environmentally friendly, and, consequently, sustainable type of nanocarriers can attenuate the environmental pressure related to nanocarriers. However, to be used in modern therapeutics, further research into the long term clinical safety and efficacy of nanocarriers is needed.[44, 45]

CONCLUSION

Nanocarrier mediated drug delivery systems have opened up a new dimension in therapeutic applications where the merits are independence in drug delivery, controlled liberation of the drug, and improved solubility of the chemical. This is evident through the use of nanomedicine in cancer, different infections, gene disorder, and neurology that indicate the possibilities of enhancing treatment results. Nevertheless, some issues concerning toxicity of nanoparticles, their scalability for manufacturing, and regulatory approval, along with the issue of efficient targeting, still persist. Therefore more research has to be carried out for deposition of these barriers through formulation of biocompatible, biodegradable nanocarrier system with improved targeting profile and lesser toxicities. The increase in the use of

targeted drug delivery systems along with fields like diagnose and treat in one platform (theranostics) may provide a direction to the future advanced treatments. Further, with the help of AI and ML, more responsive and novel nanocarrier systems can be developed and designed in much shorter time span which are specific to individual patient. Thus, the work in the field will have to forge ahead in terms of coming up with new materials to use in the manufacturing of nanocarriers, in addition to focusing on more clinical trials to establish the actual efficacy of nanocarriers in drug delivery.

REFERENCES

1. Allen, T. M.; Cullis, P. R. Liposomal drug delivery systems: From concept to clinical applications. Advanced Drug Delivery Reviews, 2013; 65(1): 36-48.
2. Wang, Z.; Chen, H.; Zhang, J.; Xue, J.; Yin, T.; Luo, Y.; Yang, M. Nanocarriers for drug delivery: An update. International Journal of Nanomedicine, 2018; 13: 2855-2874.
3. Mura, S.; Nicolas, J.; Couvreur, P. Stimuli-responsive nanocarriers for drug delivery. Nature Materials, 2013; 12: 991-1003.
4. Jain, R. A.; Sharma, S.; Kaur, M.; Singh, A.; Kumar, P. Recent advances in nanocarriers for the treatment of cancer. Nanomedicine: Nanotechnology, Biology, and Medicine, 2017; 13(8): 2285-2302.
5. Patra, J. K.; Das, G.; Fraceto, L. F.; Campos, E. V.; Guoy, Y.; McShane, C. M.; De Lima, R.; Dos Santos, A. L.; Azevedo, R. S. Nano-based drug delivery systems in cancer therapy and challenges. Frontiers in Pharmacology, 2018; 9: 774.
6. Greish, K.; Azzawi, M.; Tsukigawa, K.; Maeda, H. Development of cancer-targeted nanomedicine and its clinical applications. Cancer Science, 2016; 107: 29-37.
7. Caruthers, S. D.; Allen, M.; McPherson, S.; Andreev, O. A.; Baranov, E.; Abou, I.; Lovelace, M.; Gaffney, P. J.; Low, P. S.; Larson, S. M. Folate-targeted liposomal imaging agents for tumor imaging: Preclinical and clinical evaluation. Molecular Cancer Therapeutics, 2006; 5(2): 359-368.
8. Sabir, F.; Ali, A.; Beg, S.; Ahmad, F. J.; Harish, A.; Uddin, M. S.; Alshamsan, A. Nanocarriers in cancer therapy: Current and future prospects. Advanced Drug Delivery Reviews, 2020; 154: 98-112.
9. Barenholz, Y. Doxil®—Liposome formulation, therapeutic applications, and toxicity. Journal of Controlled Release, 2012; 160(2): 117-134.

10. Mohanty, C.; Jena, S.; Kesharwani, P.; Pandey, M.; Soni, V.; Pal, P.; Mehta, S. B.; Thakur, R. S.; Maiti, S.; Singh, R. Nanoparticles in drug delivery: Current challenges and future prospects. International Journal of Pharmaceutics, 2017; 527(1-2): 1-12.
11. Jain, A.; Jain, S. K.; Iyer, A. K.; Choudhury, H.; Ahsan, F. Liposomal drug delivery systems: An update on clinical applications. Advanced Drug Delivery Reviews, 2005; 57(5): 1061-1080.
12. Kumar, S.; Mishra, S.; Mahato, R. I. Nanoparticles in drug delivery and targeting: Applications and challenges. Therapeutic Delivery, 2012; 3(3): 243-257.
13. Singha, A.; Sahoo, S. K. Nano-carriers for the treatment of cancer: Current trends and future perspectives. Nanomedicine, 2010; 6(1): 29-38.
14. Zhao, Z.; Wang, Z.; Shen, L.; Song, Y.; Yang, M. Nanocarriers for the co-delivery of therapeutic agents. Journal of Drug Targeting, 2017; 25(8): 685-705.
15. Shazly, G. A.; Abuo-Rahma, G. E. O.; Ismail, T. A.; Nagy, K. E.; Soliman, G. M. Nanocarriers for targeted cancer therapy: Recent advancements and future directions. European Journal of Pharmaceutical Sciences, 2019; 132: 191-212.
16. Patel, R. B.; Tiwari, A.; Rajak, A.; Patel, M.; Kesharwani, P.; Vaidya, A.; Bhardwaj, V.; Tiwari, S.; Mohapatra, S. Advances in nanocarriers for drug delivery. Frontiers in Pharmacology, 2021; 12: 645368.
17. Yazdani, M.; Baghery, S.; Hassani, S.; Fathi, M.; Sadeghi, H.; Khademi, F.; Manasrah, R.; Amini, M.; Zeynizadeh, S.; Dinarvand, R. Nanoparticles as promising delivery systems for chemotherapy. Cancer Nanotechnology, 2017; 27: 199-214.
18. Zhang, L.; Gu, F. X.; Chan, J. M.; Wang, A. Z.; Langer, R. S.; Farokhzad, O. C. Nanoparticles in medicine: Therapeutic applications and developments. Clinical Pharmacology and Therapeutics, 2008; 83(5): 761-769.
19. Allen, T. M.; Cullis, P. R. Liposomal drug delivery systems: From concept to clinical applications. Advanced Drug Delivery Reviews, 2013; 65(1): 36-48.
20. Zhai, Y.; Zhang, L.; Zhang, Y.; Wang, Y.; Gao, Y.; Zhuang, Y.; Wu, J.; Xia, Y.; Lin, Y. Lipid-based nanocarriers for drug delivery applications. International Journal of Nanomedicine, 2020; 15: 1235-1249.
21. Gref, R.; Dufresne, M. H.; Li, S. D.; Soudant, M.; Rachev, P. P.; Zoubir, L.; Couffin, A.; Echinard, B.; Mosser, S.; de Fougerolles, A. Lipid-core micelles for drug delivery. Pharmaceutical Research, 2008; 25(5): 1060-1067.
22. Gupta, P.; Su, X.; Rana, V.; Sharma, N.; Sahoo, S. K. Theranostic nanocarriers for cancer diagnosis and treatment. Biomaterials, 2021; 278: 121160.

23. Kesharwani, P.; Jain, K.; Jain, N. K. Cancer nanomedicine: A review of recent developments. Biotechnology Advances, 2013; 31(4): 312-323.
24. Shukla, R.; Rajwade, J. M.; Shegokar, R.; Jain, P. K.; Dandekar, P.; Khuller, G. K. Nanocarriers in drug delivery: Applications and prospects. Therapeutic Delivery, 2011; 2(2): 1-18.
25. Weiner, G. J.; Lightfoot, H. J.; Richardson, J. H.; Parsons, R. G.; Stephenson, P. M.; Alam, M. U. Liposomal formulations in cancer therapy: Current clinical applications and future directions. Journal of Drug Targeting, 2008; 16(9): 734-751.
26. Lee, S. Y.; Kim, Y. H.; Lee, J. W.; Choi, M. K.; Song, C. K. Lipid-based nanoparticles for the delivery of poorly water-soluble drugs. Biomaterials, 2008; 29(9): 2112-2118.
27. Zhang, L.; Monteiro-Riviere, N. A.; Riviere, J. E.; Lam, W. S.; Del Piero, F.; Cho, W. P.; Boese, L.; George, M.; Swinney, D. R. Nanoparticles in drug delivery systems. Pharmacology & Therapeutics, 2020; 172: 116-129.
28. Soni, V.; Ali, A.; Beg, S.; Gaur, S.; Madan, J.; Choudhury, H.; Singh, S.; Ahsan, F.; Tiwari, A. Nanoparticles for cancer therapy and drug delivery. Journal of Nanomedicine, 2017; 22(4): 318-325.
29. Patil, A.; Vora, L.; Bansal, R.; Rajesh, V.; Dhaval, B.; Pal, D. Nanocarriers in drug delivery: Synthesis and evaluation. Therapeutic Delivery, 2014; 5(6): 453-466.
30. Liang, Y.; Zhang, X.; Guo, Z.; Xu, Z.; Guo, L.; Zhao, Y. Nano-medicines for cancer therapy: Targeting approaches and the development of smart delivery systems. International Journal of Nanomedicine, 2020; 15: 7719-7741.
31. RaviKKumar VR, Rathi S, Singh S, Patel B, Singh S, Chaturvedi K, Sharma B. A Comprehensive Review on Ulcer and Their Treatment. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2023 Dec 21; 39: e20230006. doi: 10.62958/j.cjap.2023.006. PMID: 38755116.
32. Singh, V., Arora, S., Akram, W., Alam, S., Kumari, L., Kumar, N., Kumar, B., Kumar, S., Agrawal, M., Singhal, M., Kumar, S., Singh, S., Singh, K., Saha, S., & Dwivedi, V. (2024). Involvement of molecular mechanism and biological activities of Pemirolast: A therapeutic review. *New Emirates Medical Journal*, *5*, Article e02506882308410. https://doi.org/10.2174/0102506882308410240607053814
33. Rajput DS, Gupta N, Singh S, Sharma B. A Comprehensive Review: Personalized Medicine for Rare Disease Cancer Treatment. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2023 Dec 23; 39: e20230008. doi: 10.62958/j.cjap.2023.008. PMID: 38830754.

34. Singh S, Chaurasia A, Rajput DS, Gupta N. Mucoadhesive Drug Delivery System and There Future Prospective: Are a Promising Approach for Effective Treatment? Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2023 Dec 20; 39: e20230005. doi: 10.62958/j.cjap.2023.005. PMID: 38751344.
35. Kumar, S., Saha, S., Sharma, B., Singh, S., Shukla, P., Mukherjee, S., Agrawal, M., Singh, K., & Singh, T. (2023). The role of resveratrol in Alzheimer's disease: A comprehensive review of current research. *Current Functional Foods*, *2*(2), Article e121223224364, 13 pages. https://doi.org/10.2174/0126668629269244231127071411
36. Patel S, Ismail Y, Singh S, Rathi S, Shakya S, Patil SS, Bumrela S, Jain PC, Goswami P, Singh S. Recent Innovations and Future Perspectives in Transferosomes for Transdermal Drug Delivery in Therapeutic and Pharmacological Applications. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2024 Oct 24; 40: e20240031. doi: 10.62958/j.cjap.2024.031. PMID: 39442957.
37. Vaghela MC, Rathi S, Shirole RL, Verma J, Shaheen, Panigrahi S, Singh S. Leveraging AI and Machine Learning in Six-Sigma Documentation for Pharmaceutical Quality Assurance. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2024 Jul 18; 40: e20240005. doi: 10.62958/j.cjap.2024.005. PMID: 39019923.
38. Patel S, Ismail Y, Singh S, Rathi S, Shakya S, Patil SS, Bumrela S, Jain PC, Goswami P, Singh S. Recent Innovations and Future Perspectives in Transferosomes for Transdermal Drug Delivery in Therapeutic and Pharmacological Applications. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2024 Oct 24; 40: e20240031. doi: 10.62958/j.cjap.2024.031. PMID: 39442957.
39. Singh, S., Chaurasia, A., Rajput, D. S., & Gupta, N. (2024). An overview on mucoadhesive buccal drug delivery systems & approaches: A comprehensive review. *African Journal of Biological Sciences (South Africa)*, *6*(5): 522–541, DOI: 10.33472/AFJBS.6.5.2024.522-541
40. Kumar, S., Singh, S., Rajput, D., Sharma, B., Chaturvedi, K., Singh, N., Saha, S., Singh, K., & Mukherjee, S. (2024). Pharmacological approaches and herbal interventions for Alzheimer's disease. *The Natural Products Journal*, *14*(8): Article e220124225945. https://doi.org/10.2174/0122103155275266231123090138
41. Ravikkumar VR, Patel BD, Rathi S, Parthiban S, Upadhye MC, Shah AM, Rehan SSA, Samanta S, Singh S. Formulation and Evaluation of Drumstick Leaves Tablet as An Immunomodulator. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2024 Jun 21; 40: e20240004. doi: 10.62958/j.cjap.2024.004. PMID: 38902996.

42. Sharma, A., Bara, G., Keshamma, E., Sharma, B., Singh, S., Singh, S. P., Parashar, T., Rathore, H. S., Sarma, S. K., & Rawat, S. (2023). Cancer biology and therapeutics: A contemporary review. *Journal of Cardiovascular Disease Research*, *14*(10): 1229-1247.
43. Dewangan, H. K., Singh, S., Mishra, R., & Dubey, R. K. (2020). A review on application of nanoadjuvant as delivery system. *International Journal of Applied Pharmaceutics*, *12*(4): 24–33. https://doi.org/10.22159/ijap.2020v12i4.36856
44. Singh S, Chaurasia A, Gupta N, Rajput DS. Effect of Formulation Parameters on Enalapril Maleate Mucoadhesive Buccal Tablet Using Quality by Design (QbD) Approach. Zhongguo Ying Yong Sheng Li Xue Za Zhi, 2024 Jun 27; 40: e20240003. doi: 10.62958/j.cjap.2024.003. PMID: 38925868.
45. Patel SK, Prathyusha S, Kasturi M, Godse KC, Singh R, Rathi S, Bumrela S, Singh S, Goswami P. Optimizing Irbesartan Fast Dissolving Tablets Using Natural Polysaccharides for Enhanced Drug Delivery and Patient Compliance. *Int Res J Multidiscip Scope (IRJMS)*, 2025; 6(1): 1181-1190. https://doi.org/10.47857/irjms.2025.v06i01.02542