Review

Advancements in Targeted Drug Delivery: Innovations in Liposomal, Nanoparticle, and Vesicular Systems

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Review

Advancements in Targeted Drug Delivery: Innovations in Liposomal, Nanoparticle, and Vesicular Systems

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Abstract: Targeted drug delivery has become a miraculous tool in the new millennium of medicine to deliver the greatest therapeutic action, minimize systemic side effects, and attain site-specific drug activity. This review offers advances in liposomal, nanoparticle, and vesicular drug delivery systems with emphasis on their capacity for maximal bioavailability and regulation of drug release. There has been controversy over the use of some of these other carriers such as tablet formulations, proniosomes, and other age-new carriers. Introduction of nanotechnology with biodegradable items and use of artificial intelligence has added new dimensions to patient-specific medicine based on the patient's need. In spite of these developments, regulatory problems, biocompatibility, and scale-up manufacture are concerns that persist as barriers to universal clinical use. Some of the recent technologies such as 3D-printed pharmaceuticals, stimuli-responsive nanocarriers, and drug design using artificial intelligence have the potential to bypass these concerns. Future direction is also set here in the focus on the application of green drug delivery concepts, precision medicine, and combination regimens in setting the future of targeted drug delivery systems. Through ongoing research and technology development, these technologies are poised to revolutionize medicine by maximizing therapeutic effect, reducing side effects, and maximizing drug delivery.

Keywords: targeted drug delivery; Liposomal and Nanoparticle Systems; Personalized medicine; AI in drug delivery; Biodegradable Innovations

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1. Introduction to Drug Targeting Strategies

Targeted drug delivery is a new concept in pharmaceutical science that seeks to enhance the efficacy of drugs, reduce side effects, and increase bioavailability by targeting therapeutic agents to precise sites in the body. The rationale for drug targeting seeks to remove the limitations of traditional treatments, which are systemically toxic, rapidly cleared, and non-selectively distributed [1].

Various advanced techniques have been devised to attain the goal of targeted drug delivery, such as:

1.1. Physical Targeting: Utilizes external stimuli such as magnetic fields, ultrasound, pH, or heat to modulate the release of medication at the target location [3].

1.2. Naso-Pulmonary Targeting: A targeted method for respiratory disease, wherein the drug is delivered by inhalation or nasal route to cause local effect with fewer systemic side effects [4].

Liposomal, vesicular, and nanoparticle drug delivery technologies have advanced a long way to treat diseases such as lung disease, cancer, and infection. All of these systems have the ability to attain controlled release, solubilization, as well as enhancement of stability and are future-looking potential candidates with promising prospects for therapeutic use [1,2].

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2. Liposomal and Vesicular Drug Delivery Systems

Liposomal and vesicular drug delivery systems are newer nanocarriers that have been established to increase drug bioavailability, stability, and site-specific action by taking advantage of lipid-based systems for encapsulation of the drug, targeting them in a controlled manner, and prolonging the delivery in an effort to eliminate systemic toxicity as well as augment therapeutic action [5].

2.1. Liposomal Drug Delivery

Liposomes are lipid vesicles in the shape of a sphere with one or more bilayer phospholipid that encapsulates an aqueous core. Liposomes are effective delivery agents for hydrophilic and lipophilic drugs because of the potential for high solubility and stability that reduces decomposition by physiological conditions [6].

Table 1. Liposomal Drug Delivery: Key Advantages [7].

Feature	Benefit
PEGylation	Extends circulation time, prevents rapid clearance
Ligand Conjugation	Enables site-specific targeting using antibodies/peptides
Reduced Toxicity	Protects healthy tissues from high drug concentrations

2.2. Proniosomes and Vesicular Systems

Proniosomes are precursors of niosomes, which upon hydration form vesicular nanocarriers that can encapsulate drug delivery agents. They provide enhanced stability and simpler storage compared to traditional liposomes and niosomes [8]. The vesicular systems are researched to a large degree for their use in transdermal, oral, and target drug delivery [9].

Table 2. Applications of Liposomal and Vesicular Carriers in Drug Targeting.

Therapeutic Area	Application	Key Benefits	References
Cancer Therapy	Liposomal doxorubicin, paclitaxel formulations	Improved efficacy, reduced systemic toxicity	[10]
Infectious Diseases	Liposomal antibiotics, antifungal formulations	Enhanced drug penetration to infection sites	[11]
Neurological Disorders	Liposomes for Alzheimer's, Parkinson's treatment	Better blood-brain barrier penetration	[10,11]
Pulmonary Drug Delivery	Inhalable liposomes for asthma, tuberculosis	Increased lung retention time, targeted therapy	[12]

3. Nanoparticle-Based Drug Delivery Systems

Nanoparticle drug delivery has transformed modern medicine by offering greater bioavailability, controlled release, and target-specific action. The nanocarriers, typically 1-100 nm in diameter, facilitate the entry of drugs past biological barriers and site-specific activity with diminished toxicity and better therapeutic effectiveness [13].

Table 3. Types of Nanoparticles in Drug Delivery [14].

Nanoparticle Type	Composition	Key Applications
Polymeric Nanoparticles	Biodegradable polymers (e.g., PLGA, chitosan)	Sustained drug release, improved drug stability
Metallic Nanoparticles	Gold, silver, iron oxide	Antibacterial, anticancer, bioimaging
Lipid Nanoparticles	SLNs, NLCs, liposomes	Enhanced solubility, improved stability, drug targeting

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Quantum Dots & Magnetic NPs	Semiconductor materials, magnetic nanoparticles	Imaging, diagnostics, stimuli-responsive drug release

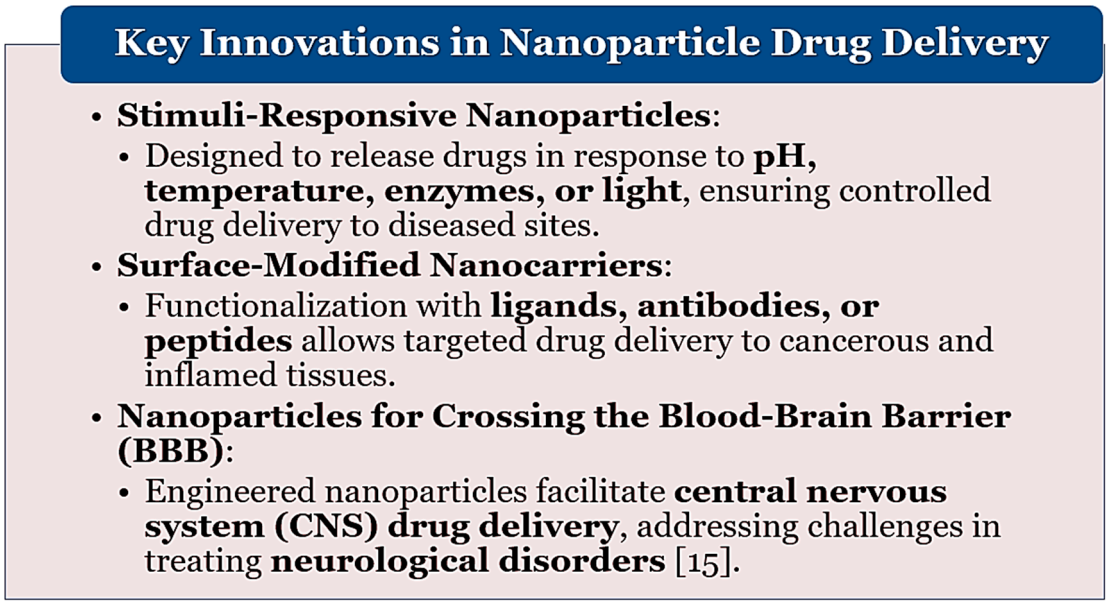

Figure 1. Key Innovations in Nanoparticle Drug Delivery [15].

3.1. Future Applications and Therapies

Nanoparticle-based drug delivery opened vast new areas in:

3.1.1 Cancer Therapy: Nanocarriers provide enhanced drug delivery to the tumorous tissue at reduced systemic toxicity.

3.1.2 Neurological Diseases: Therapeutic nanoparticles are utilized to target drug delivery to the brain for treating Alzheimer's, Parkinson's, and glioblastomas.

3.1.3 Infectious Diseases: Metal nanoparticles also showed efficient antimicrobial activity and are used in therapy of resistant pathogens.

3.1.4 Immunodeviction Vaccine Delivery: Nanoparticle-vaccines like COVID-19 mRNA vaccines deliver strong immunresponse and shelf-stability [16,17].

Through developing science, wise, ecofriendly, multi-capable nanoparticles shall lead to precision medicine for high-level added therapeutic effectiveness coupled with high level compliance by the patients [13–16].

4. New Horizon for Formulation Strategy: Tablets, Proniosomes, Alternative Carriers

The development of formulation methods has been successful in achieving significant enhancement in the stability of drugs, bioavailability, and compliance of patients. Newly developed dosage forms such as chewable tablets, proniosomes, and other vesicular carriers have been formulated to achieve the desired therapeutic effect [18].

Table 4. Advanced Drug Delivery Systems.

Category	Description	Key Benefits	Reference
Tablet-Based Drug Delivery	Includes chewable, effervescent, and mouth-dissolving tablets	Improved patient compliance, rapid drug absorption	[19]
Proniosomes & Vesicular Carriers	Stable precursors to niosomes for enhanced drug encapsulation and release	Increased bioavailability, controlled drug release	[20]

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Nanoemulsions	Oil-in-water or water-in-oil dispersions for solubility enhancement	Better drug solubility and permeability	[21]
Lipospheres & SLNs	Lipid-based nanoparticles for targeted drug delivery	Reduced systemic toxicity, improved drug targeting	[21]
Hybrid Nanocarriers	Combination of multiple delivery mechanisms	Enhanced drug loading and sustained release	[21]

5. Personalized Medicine and Smart Drug Delivery: AI, Nanotechnology, and Biodegradable Innovations

Personalized medicine is revolutionizing drug delivery by personalizing therapeutic interventions to an individual patient according to genetic, environmental, and lifestyle factors. Involvement of artificial intelligence (AI), nanotechnology, and biodegradable carriers for drugs has also contributed significantly towards precision in targeted drug delivery and disease control [22].

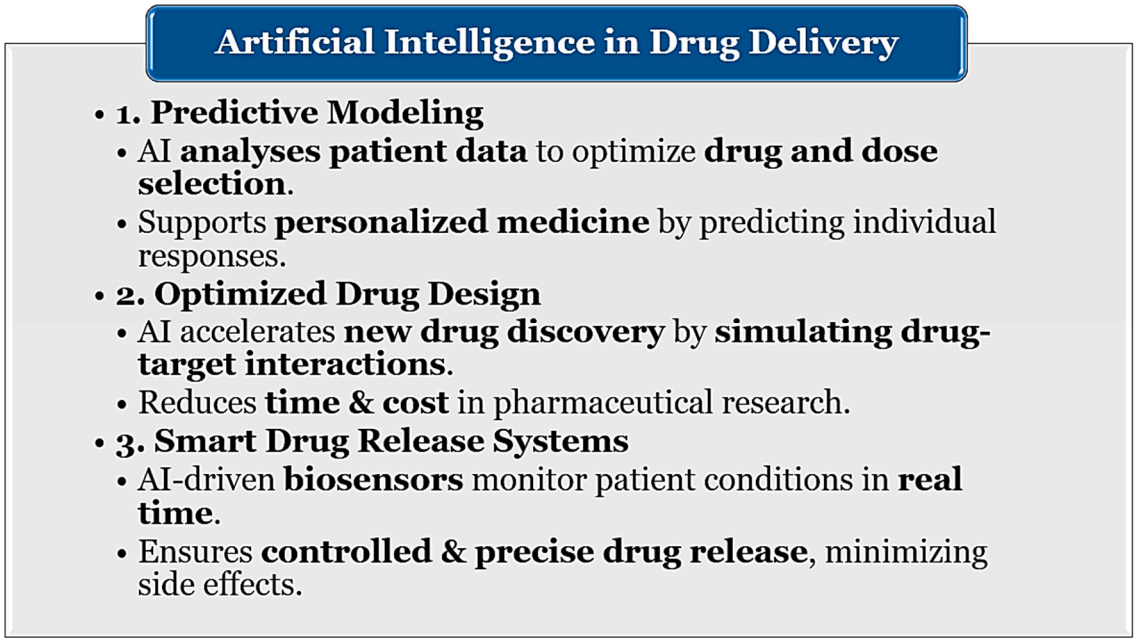

Figure 2. AI in Drug Delivery [23].

Table 5. Innovations in Nanotechnology and Biodegradable Drug Carriers [24,25].

Category	Description	Key Benefits
Nano-Carriers for Cancer Therapy	Targeted drug delivery using nanoparticles	Reduced toxicity, enhanced efficacy
Liposomes & Polymeric Nanoparticles	Controlled drug release carriers	Improved drug retention, prolonged action
Nanosensors in Diagnostics	Nanotechnology-based biosensors for early disease detection	Personalized treatment, early intervention
Biodegradable Drug Carriers	Sustainable polymer-based delivery systems	Eco-friendly, controlled release, minimal side effects
Hydrogel-Based Carriers	Smart hydrogels for drug encapsulation and release	Responsive drug delivery, regenerative medicine applications

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6. Future Perspectives and Challenges in Targeted Drug Delivery

Targeted drug delivery technology is driven ahead by breakthrough discoveries, but some of it still has to break through challenges. Emerging technologies will improve efficacy and selectivity as well as safety and break through primary drug design and patient-targeted treatment hurdles [26,27].

Table 6. Innovations and Challenges in Targeted Drug Delivery [26,27].

Category	Description	Key Benefits/Challenges
Smart Nanocarriers	Stimuli-responsive carriers release drugs based on pH, temperature, or enzymes	Precise drug targeting, controlled release, minimal side effects
Gene & Cell-Based Therapies	CRISPR and cell therapies for genetic disorders and cancer	Requires stable and specific delivery systems
3D-Printed Drug Formulations	Personalized medicine with custom drug dosing and combinations	Improved patient adherence and treatment outcomes
Biocompatibility & Toxicity Concerns	Some nanocarriers pose toxicity risks	Requires extensive safety evaluations
Scalability & Manufacturing	High production costs and complex fabrication methods	Challenges in transitioning from lab to large-scale production
Regulatory Hurdles	Novel systems require strict testing and approval processes	Prolonged development timelines
Patient-Specific Variability	Individual differences impact drug response	AI-driven models needed for optimized treatments

Conclusion

Targeted drug delivery transformed modern therapeutics in efficacy, specificity, and patient safety. Liposomal, nanoparticle, and vesicular systems next generation improved bioavailability, controlled release, and site-specific action by orders of magnitude. Improved tablet design, proniosomes, and non-conventional carriers optimized drug delivery option and specifically tailored for different clinical requirements. Nanotechnology convergence, biocompatible materials, and AI also optimized medicine to provide adaptive and personalized therapy. Despite over biocompatibility, scalability, and regulatory problems, the science is moving forward with AI-facilitated drug development, 3D-printed drugs, and smart nanocarriers. Future development will be in the form of combination, AI-driven, and green therapies with possibilities of next-generation targeted drug delivery systems that are safe, effective, and personalized to the patient's requirement.

References

1. **Sengar, A. (2023).** Targeting methods: A short review including rationale, goal, causes, strategies for targeting. *International Journal of Research Publication and Reviews, 4(8),* 1379-1384. ISSN 2582-7421.
2. **Jagrati, K. M., & Sengar, A. (2024).** Liposomal vesicular delivery system: An innovative nano carrier. *World Journal of Pharmaceutical Research, 13(13),* 1155-1169. https://doi.org/10.20959/wjpr202413-32990
3. **Prajapati, R. N., Jagrati, K., Sengar, A., & Prajapati, S. K. (2024).** Nanoparticles: Pioneering the future of drug delivery and beyond. *World Journal of Pharmaceutical Research, 13(13),* 1243-1262.
4. **Sengar, A., Jagrati, K., & Khatri, S. (2024).** Enhancing therapeutics: A comprehensive review on naso-pulmonary drug delivery systems for respiratory health management. *World Journal of Pharmaceutical Research, 13(13),* 1112-1140.
5. **Sengar, A., Vashisth, H., Chatekar, V. K., Gupta, B., Thange, A. R., & Jillella, M. S. R. S. N. (2024).** From concept to consumption: A comprehensive review of chewable tablets. *World Journal of Pharmaceutical Research, 13(16),* 176-189.

6. **Sengar, A., Yadav, S., & Niranjan, S. K. (2024).** Formulation and evaluation of mouth-dissolving films of propranolol hydrochloride. *World Journal of Pharmaceutical Research, 13(16),* 850-861.
7. **Sengar, A., Tile, S. A., Sen, A., Malunjkar, S. P., Bhagat, D. T., & Thete, A. K. (2024).** Effervescent tablets explored: Dosage form benefits, formulation strategies, and methodological insights. *World Journal of Pharmaceutical Research, 13(18),* 1424-1435.
8. **Sengar, A., Saha, S., Sharma, L., Hemlata, Saindane, P. S., & Sagar, S. D. (2024).** Fundamentals of proniosomes: Structure & composition, and core principles. *World Journal of Pharmaceutical Research, 13(21),* 1063-1071.
9. **Sengar, A. (2024).** Liposomes and Beyond: Pioneering Vesicular Systems for Drug Delivery. *Preprints.* https://doi.org/10.20944/preprints202412.2230.v1
10. **Sengar, A. (2024).** Precision in Practice: Nanotechnology and Targeted Therapies for Personalized Care. *International Journal of Advanced Nano Computing and Analytics, 3(2),* 56-67.
11. **Sengar, A. (2025).** Liposomal Drug Delivery Systems: An Intro as a Primer for Advanced Therapeutics. *Preprints.* https://doi.org/10.20944/preprints202501.0398.v1
12. **Sengar, A. (2025).** Innovations and Mechanisms in Liposomal Drug Delivery: A Comprehensive Introduction. *Preprints.* https://doi.org/10.20944/preprints202501.0206.v1
13. **Sengar, A., Chatekar, V. K., Andhare, S. B., & Sharma, L. (2025).** Clinical pharmacology of antibiotics: Mechanisms, therapeutic uses, and resistance patterns. *World Journal of Pharmaceutical Research, 14(1),* 1531–1545. https://doi.org/10.20959/wjpr20251-35216
14. **Sengar, A. (2025).** Targeting Strategies in Liposomal Drug Delivery. *Preprints.* https://doi.org/10.20944/preprints202501.0866.v1
15. **Sengar, A. et al. (2025).** Advancing urolithiasis treatment through herbal medicine: A focus on *Tribulus terrestris* fruits. *World Journal of Pharmaceutical Research, 14(2),* 91–105.
16. **Sengar, A. (2025).** Next-Generation Liposomal Drug Delivery Systems: Core Principles, Innovations, and Targeting Strategies. *Preprints.* https://doi.org/10.20944/preprints202501.1875.v1
17. **Sengar, A. (2025).** Advanced Targeting Strategies and Applications of Liposomal Drug Delivery Systems. *Preprints.* https://doi.org/10.20944/preprints202501.2091.v1
18. **Sengar, A. (2025).** Innovations and Mechanisms in Liposomal Drug Delivery: A Comprehensive Introduction. *J Emerg Med OA, 3(1),* 01-05.
19. **Sengar, A. (2025).** Historical Evolution and Modern Advances in Vesicular Nanocarriers. *Preprints.* https://doi.org/10.20944/preprints202501.2323.v1
20. **Sengar, A. (2025).** The Interplay of Drug Delivery Systems: A Comparative Study of Nanocarriers and Vesicular Formulations. *Preprints.* https://doi.org/10.20944/preprints202502.0022.v1
21. **Sengar, A. (2025).** Innovations in Drug Delivery and Advanced Therapeutics. *Preprints.* https://doi.org/10.20944/preprints202502.0156.v1
22. **Sengar, A. (2025).** Personalized Medicine and Nanotechnology: Transforming Modern Therapeutics. *Preprints.* https://doi.org/10.20944/preprints202502.0744.v1
23. **Sengar, A. (2025).** Advancements in Drug Delivery Systems: Targeting Strategies, Nanotechnology, and Vesicular Innovations. *Preprints.* https://doi.org/10.20944/preprints202502.0849.v1
24. **Sengar, A. (2025).** Precision in Practice: Nanotechnology and Targeted Therapies for Personalized Care. *Preprints.*
25. **Sengar, A. (2025).** Next-Gen Drug Delivery: Redefining Precision, Bioavailability, and Therapeutic Outcomes. *Preprints.* https://doi.org/10.20944/preprints202502.1230.v1
26. **SENGAR, A. (2025).** Smart Drug Delivery: AI, Nanotech & Future Innovations. *Preprints.* https://doi.org/10.20944/preprints202502.1421.v1
27. **Ashutosh, S. (2025).** Sustainable Drug Delivery Systems with Biodegradable Innovations for Targeted and Efficient Therapy. *Preprints.* https://doi.org/10.20944/preprints202502.1489.v1