OPEN ACCESS Freely available online

Biochemistry & Pharmacology: Open Access

Commentary

Advanced Nanocarrier-Based Drug Delivery Systems: Biochemical Principles and Pharmacological Applications

Catarina Moura*

Department of Nanotechnology, University of Lisbon, Lisbon, Portugal

DESCRIPTION

Nanocarrier-based drug delivery systems have emerged as one of the most promising technologies in modern pharmaceutical science. Their ability to improve the bioavailability, targeted delivery, and controlled release of therapeutics offers substantial benefits over conventional drug delivery approaches. These nanocarriers ranging from liposomes, dendrimers, polymeric nanoparticles, micelles, to solid lipid nanoparticles are engineered to encapsulate drugs, protect them from degradation, and transport them across biological barriers to specific target sites. The fundamental biochemical principles behind their operation involve the exploitation of nanoscale interactions, surface modifications with ligands for active targeting, and responsiveness to internal (pH, redox) or external (temperature, magnetic field) stimuli for controlled drug release.

One of the primary biochemical advantages of nanocarriers is their capability to overcome physiological barriers such as the blood-brain barrier, which has traditionally posed challenges in the treatment of neurological diseases. Functionalizing nanocarriers with ligands such as transferrin, lactoferrin, or antibodies enhances their binding affinity to receptor-mediated transport systems on endothelial cells, facilitating drug passage into the brain parenchyma. Additionally, nanocarriers can improve pharmacokinetic profiles by increasing the half-life of drugs in circulation and reducing their systemic toxicity. For example, PEGylation attaching polyethylene glycol chains to the surface helps nanocarriers evade immune detection, extending their systemic presence and therapeutic effect.

Pharmacologically, these systems allow for the delivery of both hydrophilic and hydrophobic drugs, biological agents like siRNA, mRNA, and proteins, as well as gene editing tools such as CRISPR-Cas9. The versatility of the nanocarrier platform enables fine-tuning of particle size, surface charge, and release kinetics to suit the specific properties of the drug and its intended therapeutic application. This has led to the successful development of nanocarrier-based drugs approved for clinical use, such as Doxil® (liposomal doxorubicin) for cancer therapy and Onpattro (siRNA-loaded lipid nanoparticle) for treating hereditary transthyretin-mediated amyloidosis.

In cancer therapy, nanocarriers play a vital role in enhancing the efficacy and reducing the side effects of chemotherapeutic agents. Tumor-targeting can be achieved via the enhanced permeability and retention effect or through active targeting using surface ligands like folic acid or antibodies against HER2 or EGFR. Once localized in the tumor tissue, the acidic microenvironment or intracellular enzymes can trigger the release of the therapeutic payload, minimizing damage to surrounding healthy tissues. Moreover, multidrug-resistant cancers have shown improved sensitivity to nanocarrier-based formulations, as these systems bypass traditional efflux mechanisms through endocytotic uptake pathways. In the treatment of infectious diseases, particularly antibiotic-resistant bacterial infections, nanocarriers are being used to enhance the delivery and efficacy of antimicrobial agents. By targeting infected cells or biofilms specifically, they reduce the required dosage and prevent systemic toxicity. Similarly, nanocarrier systems are being explored for vaccine delivery, especially in the context of mRNA vaccines, as exemplified by the COVID-19 pandemic. Lipid nanoparticles enabled the safe and effective delivery of fragile mRNA sequences into host cells, marking a significant breakthrough in vaccinology.

Despite their advantages, nanocarrier systems also face challenges including scale-up difficulties, regulatory hurdles, and potential long-term toxicity due to accumulation in organs such as the liver or spleen. Moreover, the variability in biological responses between individuals necessitates further research into personalized nanomedicine approaches. The complexity of biological systems means that even minor variations in nanocarrier design can significantly impact biodistribution and therapeutic outcomes.

CONCLUSION

In advanced nanocarrier-based drug delivery systems represent a transformative approach in the field of pharmacology. By leveraging the principles of biochemistry and molecular

Correspondence to: Catarina Moura, Department of Nanotechnology, University of Lisbon, Lisbon, Portugal, E-mail: c.moura.nano@unilisboa.pt

Received: 03-Feb-2025, Manuscript No. BCPC-25-37574; **Editor assigned:** 05-Feb-2025, PreQC No. BCPC-25-37574 (PQ); **Reviewed:** 19-Feb-2025, QC No. BCPC-25-37574; **Revised:** 26-Feb-2025, Manuscript No. BCPC-25-37574 (R); **Published:** 04-Mar-2025. DOI: 10.35248/2167-0501.25.14.382

Citation: Moura C (2025). Advanced Nanocarrier-Based Drug Delivery Systems: Biochemical Principles and Pharmacological Applications. Biochem Pharmacol.14:382.

targeting, these systems significantly improve the therapeutic index of drugs while minimizing adverse effects. Their adaptability for delivering a wide range of therapeutic agents positions them at the forefront of precision medicine. Continued interdisciplinary research in materials science, molecular biology, and pharmacokinetics will be crucial to overcome existing limitations and fully realize the clinical potential of nanocarrier technologies. The future of drug delivery is undoubtedly being shaped by the continued advancement of these nanoscale platforms.