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LIPOSOMAL DRUG DELIVERY: CURRENT TRENDS AND APPLICATIONS

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Abstract

Liposomal drug delivery systems represent a significant advancement in modern pharmacotherapy, providing controlled and targeted delivery of both hydrophilic and hydrophobic drugs. Due to their biocompatibility and ability to encapsulate various therapeutic agents, liposomes have found applications across oncology, infectious diseases, and gene therapy. This review explores the classification of liposomes, advances in drug loading strategies, surface modifications, clinical uses, and future research directions. While several formulations have already gained FDA approval, challenges in manufacturing, stability, and regulatory approval persist. Ongoing innovations, such as stimuli-responsive liposomes and personalized Nano medicine, are poised to further elevate liposomes as a cornerstone in drug delivery technology.

Keywords: Liposomes, Drug Delivery, PEGylation, Targeted Therapy, Nano medicine, Controlled Release

1. Introduction

Liposomal drug delivery systems have garnered attention due to their structural similarity to biological membranes and their ability to encapsulate a variety of drug molecules (Allen & Cullis, 2013). Since their discovery in the 1960s by Alec Bangham, liposomes have evolved from simple bilayer structures into complex Nano carriers tailored for precision medicine (Barenholz, 2012). Their versatility allows encapsulation of both hydrophilic drugs within the aqueous core and lipophilic drugs within the bilayer membrane (Sercombe et al., 2015).

2. Structure and Classification of Liposomes

Liposomes are composed primarily of phospholipids and cholesterol. They are categorized based on size and number of bilayers:

- **Small Unilamellar Vesicles (SUVs):** 20–100 nm
- **Large Unilamellar Vesicles (LUVs):** >100 nm
- **Multilamellar Vesicles (MLVs):** Multiple lipid bilayers

Advanced types include:

- **PEGylated Liposomes (Stealth Liposomes):** Reduced immune recognition (Torchilin, 2005)
- **Targeted Liposomes:** Functionalized with ligands or antibodies (Bozzuto & Molinari, 2015)
- **Stimuli-responsive Liposomes:** Release triggered by pH, enzymes, or temperature (Pattni et al., 2015)

3. Drug Loading Techniques

3.1 Passive Loading

This method involves entrapping drugs during vesicle formation. While simple, passive loading often results in lower encapsulation efficiency (Zhang, 2019).

3.2 Active Loading

Active or remote loading utilizes ion gradients to achieve high drug-to-lipid ratios. For example, doxorubicin is loaded using an ammonium sulfate gradient in Doxil® (Barenholz, 2012).

4. Advances in Liposomal Formulation

4.1 PEGylation

Surface PEGylation prevents recognition by opsonins, extending circulation time and improving tumour targeting through the enhanced permeability and retention (EPR) effect (Allen et al., 1991; Immordino et al., 2006).

4.2 Ligand-Targeted Liposomes

Ligands such as folic acid or monoclonal antibodies are used to direct liposomes to cancer cells overexpressing specific receptors (Nogueira et al., 2015).

4.3 Stimuli-Responsive Liposomes

Smart liposomes respond to:

- **Acidic pH** (tumour microenvironment)
- **Heat** (thermosensitive liposomes)
- **Enzymes** (e.g., MMPs in cancer tissue)
  (Torchilin, 2005; Danaei et al., 2018)

5. Clinical Applications

5.1 Oncology

- **Doxil®:** Used in ovarian and breast cancer (Barenholz, 2012)
- **Onivyde®:** Liposomal irinotecan for pancreatic cancer (Silverman & Deitcher, 2013)

5.2 Infectious Diseases

- **AmBisome®:** Liposomal amphotericin B reduces nephrotoxicity (Bulbake et al., 2017)
- **DepoCyt®:** Used for lymphomatous meningitis

5.3 Vaccinology

Liposomal adjuvants like **AS01** improve immune response, used in vaccines such as Shingrix® (Zhang et al., 2013).

5.4 Gene Delivery

Cationic liposomes deliver siRNA and mRNA. Lipid nanoparticles used in COVID-19 mRNA vaccines are a subclass of these systems (Kulkarni et al., 2018).

6. Challenges and Limitations

- **Stability:** Susceptible to oxidation and leakage (Akbarzadeh et al., 2013)
- **High Cost:** Manufacturing and scale-up remain expensive
- **Drug Leakage:** Especially for hydrophilic agents
- **Complex Regulations:** Nano medicine-specific pathways still developing (Cagel et al., 2017)

7. Future Directions

- **Smart Liposomes:** Combining diagnostics and therapy (theranostics)
- **AI-assisted Formulation:** Predictive modelling for drug behaviour (Zhang et al., 2013)
- **Personalized Nano medicine:** Tailored formulations based on genetic markers
- **Hybrid Nano carriers:** Combination with polymers or dendrimers (Vemuri & Rhodes, 1995)

8. Conclusion

Liposomal drug delivery offers immense therapeutic potential with numerous clinical successes. While barriers remain, such as cost and regulatory complexity, advancements in materials science, artificial intelligence, and precision medicine are ushering in a new era for liposomal systems. Future developments will likely focus on multifunctional, targeted, and patient-specific therapies.

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