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LIPOSOMAL DRUG DELIVERY SYSTEMS: A COMPREHENSIVE REVIEW OF CHARACTERIZATION AND CLINICAL APPLICATIONS

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1. ABSTRACT

Liposomes have revolutionized the field of pharmaceutics by providing a versatile platform for the delivery of both hydrophilic and lipophilic drugs. This review explores the structural components of liposomes, primarily phospholipids and cholesterol, and their role in enhancing drug stability and bioavailability. We discuss various preparation methods, from traditional thin-film hydration to modern microfluidic techniques. Furthermore, the review highlights the transition from conventional liposomes to "smart" delivery systems, including PEGylated (stealth) and ligand-targeted vesicles, and concludes with an overview of FDA-approved liposomal products and future market trends.

2. INTRODUCTION

The challenge of delivering drugs with poor solubility or high toxicity has led to the development of Nanoparticulate Drug Delivery Systems (NDDS). Among these, liposomes-first described by Alec Bangham in 1961-remain the most successful. Pharmaceutics focuses on these vesicles because they mimic biological membranes, making them highly biocompatible and biodegradable.

3. Classification of Liposomes

Liposomes are classified based on their size and the number of lipid bilayers (lamellae):

SUV (Small Unilamellar Vesicles): 20-100 nm

LUV (Large Unilamellar Vesicles): > 100 nm.

MLV (Multilamellar Vesicles): Several

concentric bilayers, often > 500 nm.

Advantages

Safe and Natural: They are made from natural lipids, making them safe and non-toxic for the body.

Carries Both Drug Types: They can carry both water-soluble and oil-soluble medicines at the same time.

Protects the Medicine: They shield the drug from body fluids so it does not break down too early.

Targeted Delivery: They take the drug straight to the sick cells, which helps reduce side effects.

Controlled Release: They release the medicine slowly in the body to make the effect last longer.

Disadvantages

High Cost: The raw materials and machines used to make them are very expensive

Low Stability: They can break down quickly or leak the drug if not stored under the right conditions.

Short Lifespan: They have a shorter shelf-life compared to simple tablets or capsules.

Hard to Scale Up: It is difficult to manufacture large amounts of high-quality liposomes in big factories.

5. Characterization Parameters

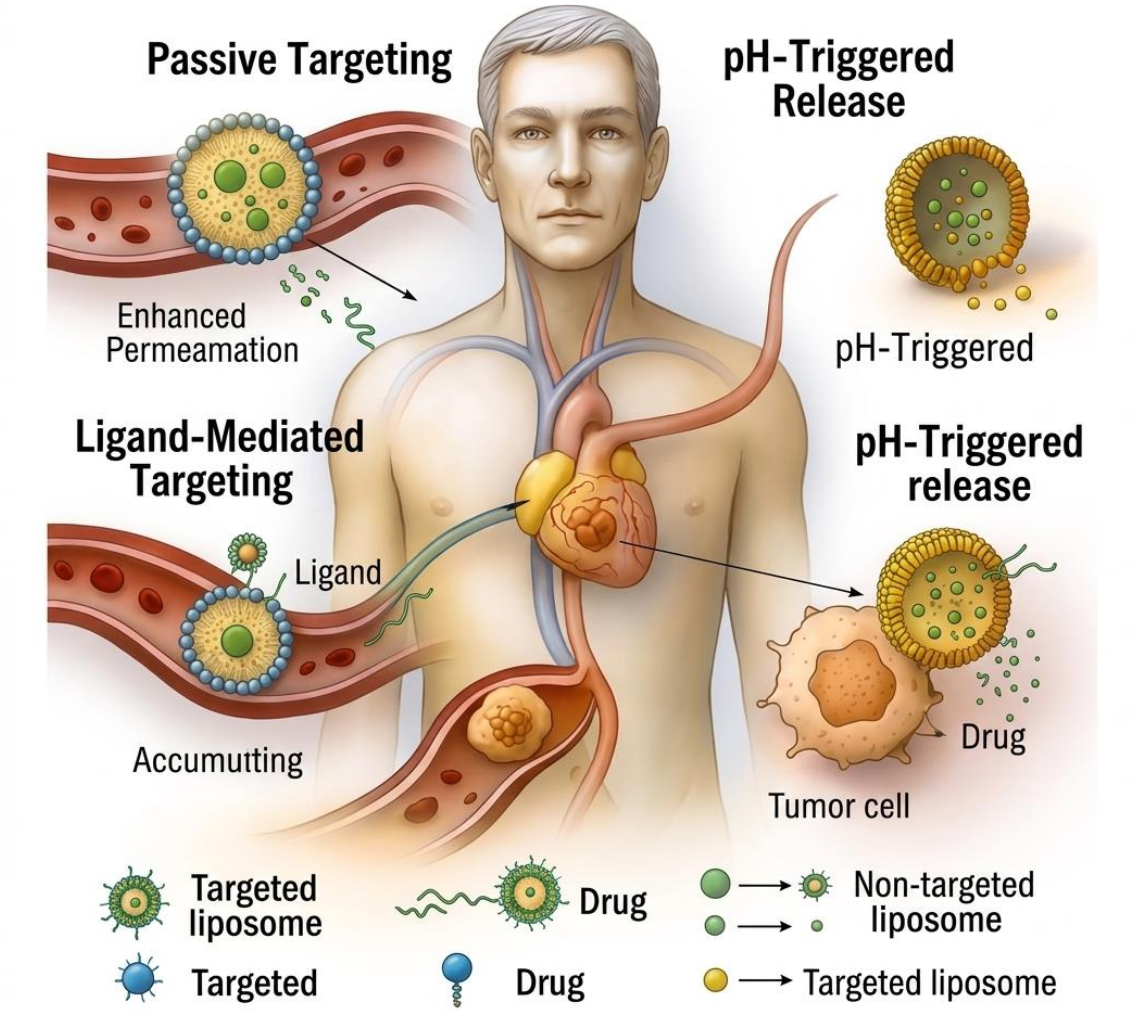
To ensure quality, the following parameters must be measured:

1. Particle Size: Determined by Dynamic Light Scattering (DLS).

2. Zeta Potential: Indicates surface charge and physical stability (values > ±30 mV suggest stability).

3. Encapsulation Efficiency (EE%): Calculated as:

$$EE\% = \frac{\text{Total Drug - Free Drug}}{\text{Total Drug}} \times 100$$



6. Clinical Applications

Oncology: Doxil (Liposomal Doxorubicin) reduces the cardiotoxicity of the drug.

Antifungal: AmBisome (Liposomal Amphotericin B) provides safer systemic treatment for fungal infections.

Vaccines: mRNA vaccines (like COVID-19 vaccines) use Lipid Nanoparticles (LNPs), a specialized type of liposomal DDS.

7. Clinical Applications: The 2026 Landscape

List the "Heavy Hitters":

Oncology: Doxil® and Marqibo®.

Infectious Disease: AmBisome®.

The Future: Theranostics (Liposomes that both treat cancer and show it on an MRI at the same time).

7. Challenges (The "Discussion" Section)

To show your "ability to express yourself," you must criticize the current state:

Stability: Lipids are prone to oxidation. How do we fix this? (e.g., Lyophilization).

The "Anti-PEG" Problem: Mention that some patients are developing antibodies against PEG (the "Stealth" coating), making the drug less effective. This is a very "smart" point to include.

Discussion and Future Trends (2025-2026 Perspective)

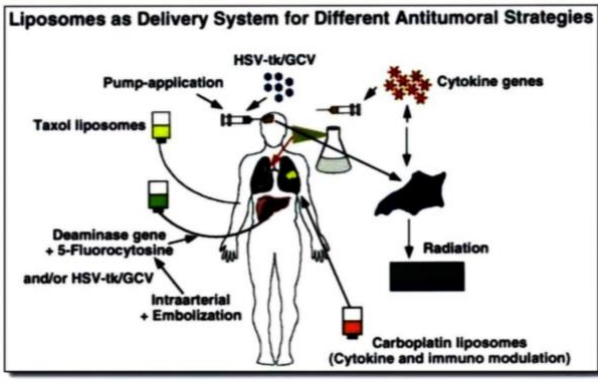
Recent advancements are focusing on Stimuli-Responsive Liposomes. These are "programmed" to release their drug cargo only when they encounter a specific trigger, such as:

pH-sensitive: Release drug in the acidic environment of a tumor.

Thermo-sensitive: Release drug when local heat is applied (hyperthermia).

Al-Integration: Using machine learning to predict the optimal lipid-to-drug ratio for maximum stability.

Chelation therapy for treatment of heavy metal poisoning.
Liposomes as Protein Carriers in Immunology
Sustained or Controlled Delivery
Diagnostic imaging of tumors
Intracellular drug delivery
Site-avoidance delivery
Site-specific targeting
Enzyme replacement
Study of membranes
Oral Drug Delivery
Gene Therapeutics
Formulation aid
Cosmetics



8. CONCLUSION

Liposomal DDS remains a cornerstone of modern pharmaceutics. While challenges in large-scale manufacturing and long-term stability persist, the development of "smart" liposomes offers a promising future for personalized medicine and targeted therapy.

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