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### Liposomes: A Promising Approach in Novel Drug Delivery System

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#### Abstract

Liposomes are spherical vesicular carriers composed of one or more phospholipid bilayers surrounding aqueous compartments. Their amphiphilic architecture permits incorporation of hydrophilic compounds within aqueous regions and lipophilic compounds within the lipid bilayer. This structural flexibility, together with biocompatibility and the ability to modify vesicle size, surface characteristics and lipid composition, makes liposomes important platforms for novel drug delivery. The source document describes liposomes as systems capable of modifying drug distribution, protecting incorporated agents, supporting controlled release and facilitating targeted delivery. It also discusses major vesicle classes, preparation methods, drug-loading approaches, evaluation parameters, pharmacokinetic considerations, therapeutic applications, stability and manufacturing challenges. Contemporary literature confirms that liposomal technology has progressed from a membrane-model concept to an established nanomedicine platform with clinically used products.

**Keywords:** Liposomes; novel drug delivery system; phospholipids; targeted delivery; controlled release; drug encapsulation; nanomedicine; liposomal formulations.

#### INTRODUCTION

Novel drug delivery systems (NDDS) are designed to overcome limitations associated with conventional dosage forms by improving drug stability, bioavailability, pharmacokinetic behavior, therapeutic performance and patient convenience. Conventional administration may be limited by frequent dosing, fluctuating plasma concentrations, poor solubility or bioavailability, rapid degradation or elimination, non-specific distribution and exposure of healthy tissues. Liposomal systems address several of these issues by incorporating the drug into a carrier whose composition and physicochemical properties can be engineered for a particular therapeutic purpose.

Liposomes were first described in the 1960s during investigations of phospholipid membrane structure. Bangham and colleagues reported closed phospholipid systems in 1965, providing the foundation for later

development of liposomes as drug carriers. Subsequent advances introduced controlled-size vesicles, remote drug loading, long-circulating formulations, triggered release and ligand-mediated targeting. [1–3]

## STRUCTURE AND COMPOSITION

A liposome consists principally of phospholipid bilayers arranged around aqueous compartments. Phospholipids are amphipathic molecules containing hydrophilic head groups and hydrophobic regions. In an aqueous environment they can self-assemble into bilayer structures, with hydrophilic groups facing water and hydrophobic chains oriented toward the interior of the membrane. The number of bilayers, vesicle size, lipid composition and surface charge influence permeability, rigidity, stability, drug retention and biological interaction.

Common phospholipids described in the source include phosphatidylcholine, phosphatidylethanolamine and phosphatidylserine, together with synthetic phospholipids such as dioleoyl phosphatidylcholine and distearoyl phosphatidylcholine. Cholesterol may be incorporated into the bilayer to influence membrane packing and stability. The final properties therefore depend on both lipid chemistry and formulation conditions. [2–4]

## CLASSIFICATION

| Type | Main feature                                                 | Drug-delivery significance                                               |
|------|--------------------------------------------------------------|--------------------------------------------------------------------------|
| MLV  | Multiple concentric bilayers                                 | Useful for loading both aqueous and lipid-soluble compounds              |
| OLV  | Few concentric bilayers                                      | Intermediate lamellarity between uni- and multilamellar systems          |
| ULV  | Single phospholipid bilayer                                  | Widely used where defined size and controlled characteristics are needed |
| MVV  | Multiple internal aqueous vesicles within one outer membrane | Can provide high aqueous encapsulation and prolonged release             |

The source document emphasizes classification according to lamellarity and size. Terminology and size ranges can vary among references; therefore, classification should be stated together with the specific preparation method and measurement technique when reporting research results.

## DRUG ENCAPSULATION AND LOADING

One of the principal advantages of liposomes is their capacity to accommodate drugs with different physicochemical properties. Hydrophilic drugs are mainly associated with the aqueous core, whereas lipophilic drugs preferentially partition into the hydrophobic region of the bilayer. Amphiphilic drugs may distribute between the aqueous and lipid domains depending on their properties and the formulation environment.

Drug loading may be achieved during vesicle formation or after formation by active or remote-loading strategies. Remote loading uses a transmembrane chemical or ion gradient as a driving force to move suitable drug molecules into preformed vesicles. This approach can improve loading efficiency for selected drugs and can contribute to drug retention within the carrier. [3,4]

## MECHANISMS OF LIPOSOMAL DRUG DELIVERY

Following administration, a liposomal formulation undergoes a sequence of events: drug incorporation, administration, circulation, distribution, target-site accumulation or recognition, cellular interaction, uptake, drug release and pharmacological action. The actual pathway depends on particle size, surface properties, lipid composition, route of administration, biological environment and the target tissue.

**Absorption:** Liposomes may attach to a cell surface through electrostatic or hydrophobic interactions, followed by local release and diffusion of drug. **Fusion:** the liposomal membrane can merge with a cellular membrane and release contents into the cytoplasm. **Endocytosis:** cells internalize vesicles into endosomal compartments where degradation or destabilization can release the drug. **Lipid exchange:** lipid components can interact with cellular membranes or lipoproteins and contribute to gradual transfer. **Controlled release:** drug release may occur through diffusion, membrane destabilization, degradation or fusion. **Targeting:** passive accumulation and active ligand-mediated recognition can alter distribution toward selected tissues or cells.

## METHODS OF PREPARATION

The choice of preparation method is influenced by desired vesicle size, number of lamellae, drug properties, lipid properties, intended route, stability and scale-up requirements. Common methods summarized in the source include thin-film hydration, reverse-phase evaporation, ethanol injection, ether injection, detergent removal, sonication, extrusion and freeze-thaw processing.

**Thin-film hydration.** Lipids are dissolved in an organic solvent, the solvent is removed to form a lipid film, and the film is hydrated with an aqueous phase. Subsequent size-reduction or homogenization steps may be used according to the required vesicle characteristics.

**Reverse-phase evaporation.** A water-in-oil emulsion is formed from phospholipids, organic solvent and aqueous phase, followed by controlled removal of solvent. The method can provide high encapsulation of aqueous-phase materials but exposes the formulation to organic solvent and requires careful processing.

**Ethanol/ether injection.** Lipids dissolved in a suitable organic solvent are introduced into an aqueous phase, after which solvent removal and vesicle formation occur. Solvent residues, size heterogeneity and possible effects on sensitive biomolecules are important considerations.

**Sonication and extrusion.** Mechanical energy can reduce vesicle size, while membrane extrusion can produce more uniform vesicle populations. Sonication may generate heat and may be associated with degradation or contamination risks if poorly controlled.

**Detergent removal and freeze-thaw methods.** Detergent-containing mixed micelles can be converted to vesicles by removing detergent through dialysis, adsorption or related approaches. Repeated freezing and thawing can promote fusion and reorganization of vesicles, often followed by additional size-control steps.

## EVALUATION OF LIPOSOMES

Important quality attributes include particle size, polydispersity index, morphology, lamellarity, entrapment efficiency, drug loading, surface charge, in-vitro drug release, physical stability, chemical stability, drug leakage, pH, in-vivo performance and sterility. Particle size may influence release, biodistribution, cellular uptake, tissue penetration and pharmacokinetics. Dynamic light scattering, electron microscopy and related techniques are commonly used for characterization.

## PHARMACOKINETIC CONSIDERATIONS

Liposomes can change the pharmacokinetic behavior of an incorporated drug by altering its absorption, distribution, metabolism and excretion. The carrier can protect the drug from immediate degradation, modify tissue distribution and influence the rate at which free drug becomes available. Consequently, liposomal formulations may produce different exposure profiles from the corresponding free drug.

Particle size, surface charge, lipid composition, cholesterol content, polymer modification such as PEGylation, drug characteristics, administration route and disease state can all influence pharmacokinetics. These factors affect circulation, uptake by the mononuclear phagocyte system, tissue distribution and drug release. Pharmacokinetic assessment commonly considers half-life, clearance, volume of distribution, area under the concentration–time curve, maximum concentration and time to maximum concentration.

## ADVANTAGES AND LIMITATIONS

**Advantages.** Liposomes are biodegradable and generally biocompatible carriers capable of incorporating hydrophilic, lipophilic and amphiphilic drugs. They can protect labile compounds, provide controlled or sustained release, modify drug distribution and support passive or active targeting. Surface modification can further influence circulation and cellular interactions. These characteristics can improve therapeutic delivery while potentially reducing exposure of non-target tissues.

**Limitations.** Liposomal formulations can suffer from physical and chemical instability, aggregation, fusion, leakage, phospholipid oxidation or hydrolysis and drug degradation. Batch-to-batch variation, sterile manufacturing, cost, storage and scale-up can be challenging. The final performance is strongly dependent on formulation composition and manufacturing conditions, so laboratory-scale success does not automatically translate to industrial production.

## STABILITY, LYOPHILIZATION AND STERILIZATION

Aqueous liposomal suspensions may undergo oxidation, hydrolysis, drug leakage, aggregation and fusion during storage. Strategies described in the source include controlled temperature, protection from light and oxygen, suitable antioxidants, optimized lipid composition and lyophilization. Freeze-drying can convert an aqueous dispersion into a dry product that is reconstituted before use. The process involves freezing, primary drying and secondary drying. Cryo- or lyoprotectants such as suitable sugars may help preserve membrane integrity during processing.

For parenteral products, sterility must be achieved without compromising vesicle size, membrane integrity or drug retention. Sterile filtration can be suitable for sufficiently small vesicles, while the complete manufacturing chain must be controlled aseptically. These considerations demonstrate why sterilization is not merely a final step but part of formulation and process design.

## APPLICATIONS IN PHARMACEUTICAL AND BIOMEDICAL DELIVERY

Liposomes have been investigated across a broad range of therapeutic areas. Their ability to encapsulate and protect active substances and to modify distribution makes them relevant to oncology, anti-infective therapy, vaccines, nucleic-acid delivery, protein and peptide delivery, ocular and pulmonary administration, topical and transdermal therapy, inflammatory diseases and CNS delivery. [2–5]

**Cancer therapy:** liposomes can alter the distribution and release of anticancer agents and can be engineered for passive or active targeting. **Antifungal therapy:** liposomal amphotericin B is a clinically established example in which liposomal formulation modifies drug distribution and can reduce certain toxic effects.

**Antibacterial and antiviral delivery:** encapsulation can protect selected agents and alter tissue exposure. **Vaccines:** liposomes can carry antigens, adjuvants and nucleic acids and facilitate interaction with immune cells.

**Gene and nucleic-acid delivery:** lipid-based carriers can protect DNA, RNA and related molecules and facilitate cellular delivery. **Protein and peptide delivery:** encapsulation can provide a protective environment and support controlled release. **Ocular and pulmonary delivery:** liposomes may improve local residence and delivery when appropriately formulated. **Topical/transdermal delivery:** lipid vesicles can interact with skin and may improve deposition or penetration of selected compounds.

## **MANUFACTURING, SCALE-UP AND REGULATORY CONSIDERATIONS**

Translation of liposomal systems from laboratory research to pharmaceutical products requires control of critical quality attributes and manufacturing variables. Vesicle size distribution, lamellarity, drug loading, entrapment efficiency, release profile, chemical purity and stability are closely linked to the manufacturing process. Changes in lipid source, composition, mixing, temperature, shear and scale can alter vesicle properties and therefore potentially affect biological performance.

Classical laboratory approaches such as thin-film hydration followed by sonication or manual extrusion may be difficult to scale directly. Continuous and microfluidic manufacturing approaches are increasingly relevant because process parameters can be controlled more reproducibly and scale-up can be approached through longer operation or parallelization. Such approaches do not remove the need for formulation development, but they can support improved process control.

Regulatory development requires characterization of the carrier as well as the active pharmaceutical ingredient. For complex liposomal products, the physical characteristics of the carrier can be critical quality attributes. Product development should therefore link composition, process parameters, characterization, stability and performance. Post-approval changes require careful assessment because apparently small manufacturing changes may modify vesicle properties and in-vivo behavior.

## **RECENT ADVANCES AND FUTURE PROSPECTS**

Recent liposome research increasingly focuses on formulations that remain stable during circulation but respond selectively to conditions at the target site. Stimuli-responsive liposomes may respond to temperature, pH, enzymes or redox conditions. Thermosensitive systems can be designed to release drug after local heating, while pH-sensitive systems can exploit acidic environments associated with tumors or intracellular compartments. Ligand-targeted liposomes can incorporate antibodies, peptides, aptamers or small molecules to improve receptor-mediated binding and uptake. [2,3]

Hybrid and next-generation carriers combine the lipid-bilayer advantages of liposomes with additional materials or functions. Theranostic liposomes can carry both therapeutic and imaging agents, supporting simultaneous treatment and monitoring. Developments in lipid nanoparticle technology, including advances stimulated by nucleic-acid medicines, have also influenced the broader field of lipid-based delivery.

## **PERSONALIZED AND COMPUTATIONALLY GUIDED FORMULATION**

The source document identifies computational and personalized formulation design as an emerging direction. Molecular dynamics can be used to investigate bilayer behavior, while machine-learning approaches may help predict lipid compositions suited to particular drugs or tissues. High-throughput microfluidic screening can reduce empirical trial-and-error by enabling rapid comparison of formulation variables. In future, disease-

specific and patient-specific design may allow surface-ligand density, lipid composition and release behavior to be tailored to biological characteristics.

## CLINICAL TRANSLATION

The development of clinically used liposomal medicines demonstrates that liposomes are more than a theoretical nanocarrier. Literature reviews describe progress from early membrane studies to approved products and clinical applications in cancer, antifungal therapy and other areas. Translation has depended on advances in formulation science, remote loading, size control, long-circulating designs, manufacturing and regulatory characterization. [2–4]

Nevertheless, clinical translation remains formulation-specific. A liposomal system should not be assumed to improve every drug or route of administration. Therapeutic benefit depends on drug chemistry, lipid composition, vesicle characteristics, target biology, release kinetics, manufacturing reproducibility and safety. A rational development program therefore requires integrated physicochemical, in-vitro, pharmacokinetic and biological evaluation.

## INTEGRATED DEVELOPMENT STRATEGY FOR A LIPOSOMAL FORMULATION

A practical development pathway begins with defining the therapeutic objective and the physicochemical properties of the drug. The formulation scientist then selects suitable lipids and a preparation/loading strategy. Vesicle size, lamellarity, surface properties and drug loading are optimized according to the intended route and target. Purification removes unencapsulated drug and process-related components, after which characterization establishes whether the formulation meets predefined quality criteria.

A useful development sequence is: **therapeutic objective → drug/lipid compatibility → lipid selection → preparation method → drug loading → purification → size control → characterization → stability assessment → in-vitro release → pharmacokinetic evaluation → biological/therapeutic assessment → process optimization → scale-up and regulatory development**. This integrated approach is consistent with the source document's emphasis on linking formulation variables to performance.

## DISCUSSION

The major strength of liposomes is their structural versatility. A single platform can be adapted to different classes of drugs by changing lipid composition, bilayer characteristics, vesicle size, surface charge and loading method. Hydrophilic and lipophilic compounds can be accommodated in different regions of the carrier, while active loading can be used for selected drugs. This flexibility explains the continued interest in liposomes across conventional pharmaceuticals, biological therapeutics and emerging nucleic-acid delivery.

At the same time, the same complexity that creates therapeutic opportunities can complicate development. Liposome performance is sensitive to formulation and process variables, and physical or chemical instability can reduce shelf life or alter in-vivo behavior. Scale-up and sterilization are particularly important for parenteral products. Therefore, successful development requires robust characterization and control of critical quality attributes rather than reliance on a single performance test.

The field is also moving toward more selective delivery. Passive accumulation can exploit disease-associated vascular and tissue characteristics, whereas active targeting uses ligands to promote recognition of specific cells. Stimuli-responsive systems add another level of control by linking drug release to environmental triggers. These strategies are promising, but their clinical value depends on demonstrating reproducible targeting and meaningful therapeutic benefit rather than simply increased cellular uptake.

## KEY CHARACTERIZATION PARAMETERS

| Parameter             | Why it matters                              | Typical approaches                      |
|-----------------------|---------------------------------------------|-----------------------------------------|
| Particle size         | Influences distribution, uptake and release | DLS, PCS, microscopy                    |
| PDI                   | Describes size-distribution uniformity      | DLS-based analysis                      |
| Morphology            | Confirms vesicle structure/integrity        | TEM, SEM, cryo-TEM, AFM                 |
| Lamellarity           | Defines number of lipid bilayers            | Cryo-TEM, freeze-fracture methods       |
| Entrapment efficiency | Quantifies incorporated drug                | Separation + drug assay                 |
| Surface charge        | Affects biological interactions             | Zeta-potential analysis                 |
| Drug release          | Describes release kinetics                  | In-vitro release testing                |
| Stability             | Detects leakage/degradation                 | Physical and chemical stability studies |

For publication-quality reporting, authors should state the composition, preparation method, purification procedure, measurement technique and relevant experimental conditions alongside numerical characterization values. This improves reproducibility and makes comparison between studies more meaningful.

## CONCLUSION

Liposomes remain one of the most versatile carrier systems within novel drug delivery. Their phospholipid bilayer architecture enables incorporation of diverse therapeutic molecules and provides opportunities to modify drug stability, distribution, release and cellular interaction. The uploaded source document demonstrates the breadth of the platform, covering classification, composition, loading, preparation, mechanisms, evaluation, pharmacokinetics, applications, stability, manufacturing and future directions. These features explain why liposomes continue to occupy an important position in pharmaceutical nanotechnology.

Future progress will depend on improving reproducibility, long-term stability, scalable manufacturing and clinically meaningful targeting. Stimuli-responsive systems, ligand-directed delivery, theranostic designs, microfluidic manufacturing and computational formulation are promising areas. However, each new formulation must be evaluated as a specific pharmaceutical product, because the therapeutic performance of liposomes depends on the combined effects of drug, carrier, process, route and biological target.

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## References

- [1] Bangham AD, Standish MM, Watkins JC. Diffusion of univalent ions across the lamellae of swollen phospholipids. *J Mol Biol.* 1965;13:238–252. doi:10.1016/S00.
- [2] Torchilin VP. Recent advances with liposomes as pharmaceutical carriers. *Nat Rev Drug Discov.* 2005;4(2):145–160. doi:10.1038/nrd1632.
- [3] Allen TM, Cullis PR. Liposomal drug delivery systems: From concept to clinical applications. *Adv Drug Deliv Rev.* 2013;65(1):36–48. doi:10.1016/j.addr.2012.09.037.
- [4] Sercombe L, Veerati T, Moheimani F, Wu SY, Sood AK, Hua S. Advances and challenges of liposome assisted drug delivery. *Front Pharmacol.* 2015;6:286. doi:10.3389/fphar.2015.00286.
- [5] Barenholz Y. Doxil®—the first FDA-approved nano-drug: lessons learned. *J Control Release.* 2012;160(2):117–134. doi:10.1016/j.jconrel.2012.03.020.
- [6] Bozzuto G, Molinari A. Liposomes as nanomedical devices. *Int J Nanomedicine.* 2015;10:975–999. doi:10.2147/IJN.S68861.
- [7] Immordino ML, Dosio F, Cattel L. Stealth liposomes: review of the basic science, rationale, and clinical applications. *Int J Nanomedicine.* 2006;1(3):297–315.
- [8] Akbarzadeh A, Rezaei-Sadabady R, Davaran S, et al. Liposome: classification, preparation, and applications. *Nanoscale Res Lett.* 2013;8:102. doi:10.1186/1556-276X-8-102.