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Review on Liposomes in Drug Delivery: A Novel Approach

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Abstract

Drug delivery technologies have significantly boosted the potential for treatment of herbal medicines. Traditional herbal preparations generally struggle with instability, low absorption, and limited medicinal efficacy. Innovative herbal drug delivery systems, including transfersomes, ethosomes, niosomes, liposomes, and phytosomes, have showed promise in addressing these limitations. The solubility, stability, and bioavailability of phytoconstituents are improved by these vesicular carriers, which raises the therapeutic efficacy of herbal medications. Hydrophilic and lipophilic molecules are encapsulated in phospholipid bilayers to form liposomes, which provide targeted delivery and prolonged release. Phytosomes are intended to increase the absorption of plant extracts by forming complexes with phospholipids that increase their bioavailability. Non-ionic surfactant-based vesicles, or niosomes, offer comparable advantages to liposomes at a lower cost. Alcohol, water, and phospholipids make up ethosomes. Niosomes, which are vesicles based on non-ionic surfactants, offer comparable advantages to liposomes at a lower cost. Ethosomes, which are made up of water, alcohol, and phospholipids, allow phytoconstituents to be delivered trans dermally more effectively and penetrate the skin more deeply. For transdermal applications, transfersomes—highly deformable vesicles—offer superior skin penetration. This review explores the fundamentals, preparation techniques, and medicinal advantages of these novel vesicular delivery systems for herbal medications. These systems have a lot of potential to improve the efficacy of traditional herbal treatments by resolving issues such as the unstable, poorly soluble, and limited bioavailability of herbal ingredients. Modern nanotechnology's integration with herbal formulations is a paradigm shift that will enable future herbal medicine to offer more effective, focused, and patient-friendly treatments.

Keywords – Transdermal, Phytoconstituents, efficacy, nanotechnology, liposomes, ethosomes.

INTRODUCTION

Herbal medicines have been utilized for centuries to treat a wide variety of ailments, and their therapeutic potential continues to be recognized in modern medicine. However, despite the growing interest in herbal remedies, many bioactive compounds derived from plants face significant challenges, particularly related to poor bioavailability, stability, and solubility, which limit their therapeutic efficacy. Traditional formulations often fail to deliver these compounds effectively due to their rapid metabolism, low solubility, and inability to target specific tissues. This has led to the need for novel drug delivery systems that can improve the pharmacokinetic and pharmacodynamic properties of herbal compounds. Nanotechnology-based approaches, such as liposomes, phytosomes, niosomes, ethosomes, and transfersomes, have emerged as promising solutions to overcome these challenges and enhance the efficacy of herbal drugs. [1]

Herbal remedies are now widely acknowledged for their medicinal potential, particularly in the management of long-term conditions including diabetes, cancer, and heart disease. Due to the perceived safety and effectiveness of natural medicines, there is a growing interest in creating sophisticated drug delivery methods for herbal compositions.

Although advantageous, traditional administration methods can have drawbacks such low bioavailability, instability, and quick bioactive component breakdown. Due to these difficulties, new drug delivery strategies must be investigated, especially those that improve the therapeutic efficacy and bioavailability of herbal medications. [2], [3]

Liposome

The watery core of liposomes, which are round balls composed of some or all phospholipid bilayers, encloses a mixture of water-friendly and lipophilic molecules. Liposomes have garnered a lot of attention as drug carriers since they were first discovered in the 1960s because they are biologically compatible, bio and can protect pharmaceuticals from deterioration. The therapy outcomes have improved as a consequence. Because of their amphiphilic nature, liposomes can carry drugs that are hydrophilic as well as lipophilic inside their lipid outer layer and water core, making them versatile delivery systems for a range of bioactive compounds, including both synthetic and natural drugs. [4] In herbal medicine, liposomes have demonstrated encouraging outcomes in addressing issues related to the low stability and bioavailability of phytochemicals Liposome formulations of herbal components with low solubility and quick degradation, like curcumin, quercetin, and resveratrol, have increased absorption and therapeutic efficacy. For instance, compared to free curcumin, liposomal curcumin has demonstrated enhanced bioavailability and anticancer activity, demonstrating the potential of liposomes in the delivery of herbal medications. A small, spherical vesicle composed of at least one lipid bilayer structure, liposomes get their name via the Greek words "lipos" (fat) and "soma" (body). These vesicles share similarities with cellular membranes and can be formed through disruption of cellular membranes using techniques such as sonication. This process creates microscopic bubbles that resemble cell membranes. The membranes of liposomes primarily comprise phospholipids, particularly phosphatidylcholine, and may incorporate additional lipids. Phospholipids exhibit amphipathic properties due to their hydrophilic (water-attracting) head regions, composed of phosphate groups, and hydrophobic (water-repelling) tail regions, consisting of extended hydrocarbon chains. This unique composition enables liposomes to interact with both aqueous and non-polar environments. Liposomes serve as versatile drug delivery systems, enabling targeted administration of medicinal agents and nutrients. They are particularly effective in delivering anticancer therapies, and their applications are similar to those of lipid nanoparticles in nucleic acid-based vaccines. The controlled release of therapeutic agents from liposomes enhances drug efficacy while reducing side effects, making them a valuable tool in pharmaceutical research.[5]

Advantages of Liposomes

Liposomes are immune-immunogenic, non-toxic, biocompatible, and completely biodegradable. Both hydrophilic and hydrophobic medications can be delivered with effectiveness. o Protect the enclosed core medication from the weather. Liposome encapsulation improves the therapeutic activity of chemotherapeutic medicines by decreasing their toxic properties and increasing their stability. Liposomes are non-toxic, non-immunogenic, fully biodegradable, and biocompatible by doing this, the likelihood of adverse effects occurring at concentrations which are comparable to or less than those necessary for optimal therapeutic activity is reduced. Limit exposure to dangerous drugs to lessen the likelihood that they will reach sensitive tissues.

Disadvantages of Liposomes

It has high production.

Fusion and leakage of encapsulated drug/molecules.[6]

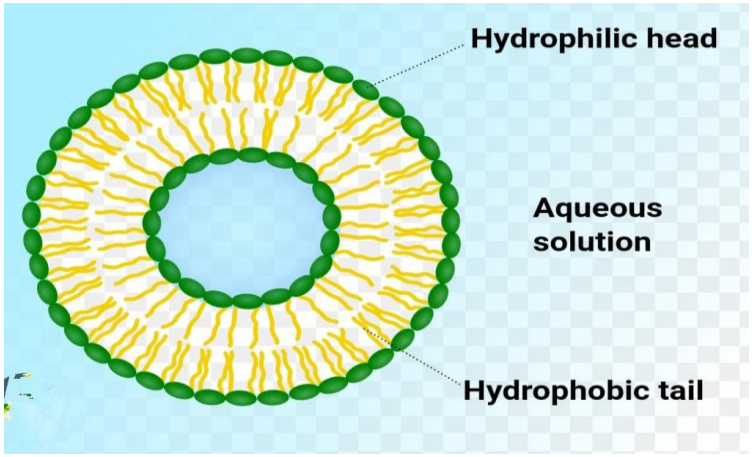

Figure 1*: *Liposome

Characteristics of Liposomes

Because of their adaptability, biocompatibility, and ability to hold both hydrophilic and hydrophobic substances, liposomes—spherical vesicles composed of lipid bilayers—are widely used as drug delivery vehicles. Their lipid composition, size, charge, and preparation technique all affect their properties.

Size and Shape

Depending on how they are prepared, liposomes can range in size from 20 nm to several micrometres. Although they usually have a spherical shape, they can occasionally take on different shapes, such as oligo- or multilamellar vesicles. Liposome biodistribution and cellular absorption are strongly influenced by their size. Due to their increased tissue penetration and decreased susceptibility to reticuloendothelial system (RES) absorption, smaller liposomes—particularly those smaller than 200 nm—have longer bloodstream circulation times. [7]

Surface Charge

Liposomes can be neutral, negatively charged, or positively charged, depending on the types of lipids used. Charged liposomes exhibit different interactions with biological membranes and proteins. Positively charged (cationic) liposomes tend to have stronger interactions with negatively charged cell membranes, making them effective in gene delivery. However, they may also induce more cytotoxic effects due to their interaction with plasma proteins and immune cells. Negatively charged liposomes, on the other hand, tend to exhibit lower toxicity but may be rapidly cleared by the RES. [8]

Encapsulation Capacity

Liposomes are a very versatile way to encapsulate hydrophilic or hydrophobic drugs. Hydrophilic drugs are found in the aqueous core, whereas hydrophobic drugs are found in the lipid bilayer. Liposomes' dual functionality makes them attractive for delivering a range of medicinal compounds. Additionally, encapsulating medications in liposomes can enhance their absorption and pharmacokinetics, lowering side effects and boosting therapeutic efficiency. [9]

Stability and Drug Release

A number of variables, including lipid composition, cholesterol level, and storage conditions, affect how stable liposomes are. Liposomes that incorporate cholesterol in their bilayers tend to be more stable as cholesterol increases membrane rigidity. Controlled drug release is a critical characteristic of liposomes, allowing for sustained drug release over time, which is highly beneficial in reducing the frequency of dosing and improving patient compliance. [10]

Biodegradability and Biocompatibility

Liposomes are biodegradable and generally biocompatible, reducing the risk of immunogenic reactions. Their lipid components can be naturally metabolized and cleared from the body, which is advantageous for clinical applications.[11]

Classification of Liposomes

Based on Structure

Liposomes are unilamellar

SUVs, or small unilamellar vesicles

Usually made up of just one lipid bilayer and ranging in diameter from 20 to 100 nm.

Large Unilamellar Vesicles (LUV)

Made of a single lipid bilayer, these particles range in size from 100 nm to 1 μm. [12]

Multiple lipid bilayers with widths varying from 100 nm to several micrometres make up multilamellar liposomes (MLV).

Based on Composition

Phospholipid-Based Liposomes

Formulated from natural or synthetic phospholipids.

Cholesterol-Containing Liposomes

Incorporate cholesterol to enhance stability and control permeability.

PEGylated Liposomes

Modified with polyethylene glycol (PEG) to improve circulation time and reduce immunogenicity. [13]

Targeted Liposomes

Functionalized with ligands or antibodies for specific targeting of cells or tissues.

Based on Charge

Cationic Liposomes

Positively charged liposomes that enhance cellular uptake through interactions with negatively charged cell membranes.

Anionic Liposomes

Negatively charged liposomes used for specific applications, including drug delivery.

Neutral Liposomes

Carry no net charge, typically less reactive and used for a variety of applications.

Based on Size

Nano-sized Liposomes

Ranging from 1-1000 nm, used in various biomedical applications.

Micro-sized Liposomes

Larger than 1 μm, often utilized in therapeutic and cosmetic formulations.

Based on Preparation Methods

Thin-Film Hydration: Lipid films are hydrated to form liposomes.

Sonication

Ultrasound is used to create smaller liposomes from larger ones.

Extrusion

Liposomal suspension is forced through filters to achieve uniform size.

Microfluidic Methods

Precise control of liposome formation through microfluidics. [14]

Based on Functionalization

Stealth Liposomes: PEGylated liposomes designed to evade the immune system.

Based on Their Application

Pharmaceutical Liposomes: Used for drug delivery, including anticancer and antifungal agents.

Cosmetic Liposomes
Deliver active ingredients in skincare products.
Vaccine Liposomes
Used as adjuvants or carriers for antigens in vaccine formulations. [15]

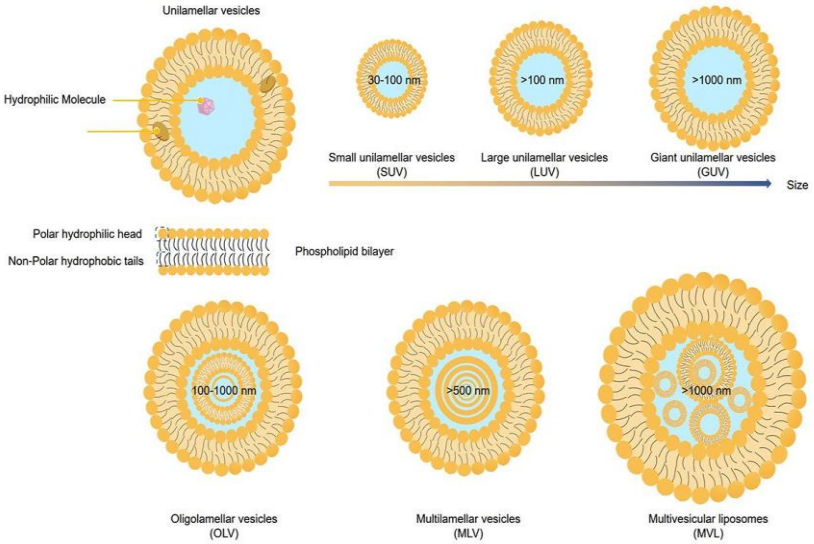

***Figure 2*:** *Schematic representation of different sizes and lamellar structures of liposomes*

Properties of Liposomes

Liposomes' Physicochemical and Biological Properties Liposomes resemble the natural shape of cell membranes in that they are spherical vesicles made up of a few lipid bilayers. Because of these special qualities, liposomes are perfect for a range of biological uses, such as delivery of medications, gene therapy, and vaccine production. A number of variables, including size, charge, lipid content, and encapsulation efficiency, influence their biological and physicochemical properties.

Biological Properties

Liposomes are vital for medicinal applications because of their biocompatibility, low in toxicity, and biodegradability. Because they resemble natural cell membranes, they can merge with target cells and transfer encapsulated molecules—like medications or genetic material—straight into the cytoplasm. A barrier that can shield hydrophilic medications in the aqueous core or hydrophobic medications within the bilayer itself is provided by the lipid bilayer composition, which is usually composed of phospholipids like phosphatidylcholine.

The ability of liposomes to avoid detection by the immune system is another essential characteristic. Liposomes can acquire "stealth" properties by being changed along with the addition of polyethylene glycol (PEG), a method called PEGylation, which decreases reticuloendothelial system (RES) clearance and lengthens bloodstream circulation time. This property is particularly beneficial in cancer therapy, where prolonged drug delivery is essential for targeting tumor cells. [16]

Physicochemical Properties

Size and Lamellarity:

The biodistribution and cellular absorption of liposomes are influenced by their size, which can vary from 20 nm to several microns. Liposomes that are smaller (50–100 nm) tend to penetrate tissues more effectively and are frequently employed in systems for drug delivery. Another classification for liposomes is multilamellar or unilamellar, depending on the number of bilayers. Multilamellar vesicles provide fewer the spaces for encapsulating medications instead of unilamellar globules which only have one lipid bilayer, because they contain multiple bilayers.

Charge

The surface charge of liposomes has a significant impact on how they interact with biological membranes. Cellular absorption is improved by strongly charged cationic liposomes because they interact with inversely charged cell membranes more efficiently. However, the immune system is more likely to get rid of them. Conversely, a neutral party and anionic liposomes tend to be more likely to be rapidly removed but may show reduced cellular uptake.

Encapsulation Efficiency

One major benefit of liposomes is their capacity to wrap up the hydrophilic and hydrophobic medications. Drugs that are hydrophobic incorporate into the lipid bilayer, whereas hydrophilic substances are kept in the aqueous core. The encapsulation efficiency depends on factors like lipid composition, preparation methods, and drug properties.

Stability

Liposome stability is influenced by factors such as lipid composition and storage conditions. Cholesterol is often incorporated into liposome formulations to enhance membrane rigidity and reduce leakage of encapsulated drugs, improving overall stability. [17]

Chemical Properties of Liposomes

Amphiphilic molecules composed of hydrophobic and hydrophilic sections, mostly phospholipids, make up liposomes. When in an aquatic environment, these characteristics enable them in order to create bilayer structures. The kinds of phospholipids that are utilized, the addition of cholesterol, the latter of and other surface alterations all affect the chemical characteristics of liposomes. Their stability, encapsulation effectiveness, and drug delivery capacities are all significantly influenced by these characteristics.

Phospholipid Composition

Phospholipids, the primary constituent of liposomes, are made up of a pair of tails of hydrophobic fatty acids and a hydrophilic head group. For example, phosphatidylcholine (PC), phosphatidylethanolamine (PE), and phosphatidylserine (PS) are often utilized phospholipids. The phospholipid selection influences the permeability and fluidity of the liposomes. The absence of double bonds in the fatty acid chains of saturated phospholipids, such as dipalmitoyl phosphatidylcholine (DPPC), results in more rigid bilayers, whereas the presence of double bonds in unsaturated phospholipids, such as dioleoyl phosphatidylcholine (DOPC), causes more fluid membranes.

Cholesterol Content

Cholesterol is commonly added to liposomal formulations to modulate membrane rigidity and stability. It intercalates between the phospholipids, reducing membrane fluidity and permeability, thereby stabilizing the liposomes and preventing leakage of encapsulated drugs. The ratio of cholesterol to phospholipids can greatly influence the overall chemical stability of the liposomal structure.

Surface Charge

Adding charged lipids like phosphatidylglycerol (PG) or phosphatidylserine (PS) to liposomes determines their surface charge. The lipid composition determines whether this charge is positive, negative, or neutral. Positively charged liposomes, which are more efficient at engaging with the negatively charged cell membranes but may also be more poisonous, are made from cationic lipids such as 1,2-dioleoyl-3-trimethylammonium-propane (DOTAP). Anionic lipids, such as dicetyl phosphate (DCP), produce negatively charged liposomes, which tend to have lower toxicity and longer circulation times in the bloodstream.

Lipid Bilayer Fluidity

The lipids' transition into phase frequency determines how fluid the lipid bilayer is. The bilayer resides in a gel condition and less permeable below the Tm, but it becomes more fluid above the transition

temperature. This property can be manipulated by selecting phospholipids with specific acyl chain lengths and degrees of saturation. Lipids with shorter chains and unsaturated bonds typically have lower Tm values, resulting in more fluid bilayers.

Encapsulation Efficiency

Liposomes' bilayer properties and lipid makeup affect how well they encapsulate medications. Hydrophobic pharmaceuticals get incorporated into the lipid bilayer, as opposed to hydrophilic drugs, which somewhat become entangled in the aqueous core.The drug's and the lipids' chemical makeup influences how the drug interacts with the liposome, which in turn influences how well the drug has been enclosed and released.

Oxidative Stability

Liposomal formulation durability and shelf life may be impacted by the oxidation susceptibility of phospholipids, especially those containing unsaturated fatty acids. The liposomal membrane's stability can be extended and oxidative breakdown can be avoided by adding antioxidants like vitamin E (α-tocopherol). [18]

Composition of Liposomes

Liposomes are multipurpose drug delivery vehicles made mostly of lipids that, in water conditions, self-assemble into bilayer structures. They may encompass either hydrophilic and hydrophobic medicinal substances because of their special composition, which improves their long-term stability and bioavailability. [19]

Phospholipids

The primary constituents of liposomes consist of: First, phospholipids Liposomes' basic building blocks are phospholipids. Their two "tails" are hydrophobic (which repel water) and hydrophilic (which attracts water) fatty acids. The choice of phospholipids has a major impact on the chemical and physical characteristics of liposomes:

Common Phospholipids

Phosphatidylcholine (PC): A widely used phospholipid that provides structural integrity and stability
Phosphatidylethanolamine (PE): Enhances the fusion ability of liposomes with cellular membranes.
Phosphatidylserine (PS): Can increase cellular uptake due to its negative charge, attracting positively charged surfaces of cells. [20]

Cholesterol

To regulate the shifting nature and resilience of the membrane, cholesterol is commonly added to liposomal compositions. Its presence alters the characteristics of the bilayer:

Membrane Rigidity

Cholesterol reduces permeability, allowing for better retention of encapsulated drugs.

Phase Transition Temperature

It raises the Tm of the liposomal membrane, providing stability across a wider temperature range. [21]

Surface Modifiers

To enhance the biocompatibility and targeting capabilities of liposomes, various surface modifiers can be added:

Polyethylene Glycol (PEG)

When conjugated to liposomal surfaces (PEGylation), it creates a hydrophilic shield that prolongs circulation time in the bloodstream and reduces immunogenicity.

Targeting Ligands: Certain peptides, antibodies, or small molecules can be attached to the liposome surface to provide targeted drug delivery to specific cells or organs.

Encapsulated Agents

Numerous medicinal substances can be encapsulated in liposomes: Drugs that are hydrophilic are usually trapped in the liposome's watery core. Proteins, nucleic acids, and tiny molecule medications are a few examples.

Hydrophobic Drugs

These are incorporated within the lipid bilayer. Common hydrophobic drugs include anticancer agents and anti-inflammatory compounds. [22]

Ionic and Non-Ionic Surfactants

To enhance liposomal stability and reduce aggregation, ionic (e.g., sodium cholate) and non-ionic surfactants (e.g., Polysorbate 80) can be used. They help in forming smaller and more uniform liposomes during preparation.

Additives

Various additives can be incorporated to improve performance:

Antioxidants

Compounds like α-tocopherol can be added to protect against lipid peroxidation and enhance shelf life.

Stabilizers

Substances like trehalose or mannitol can help maintain liposome structure during freeze-drying or long-term storage. [23]

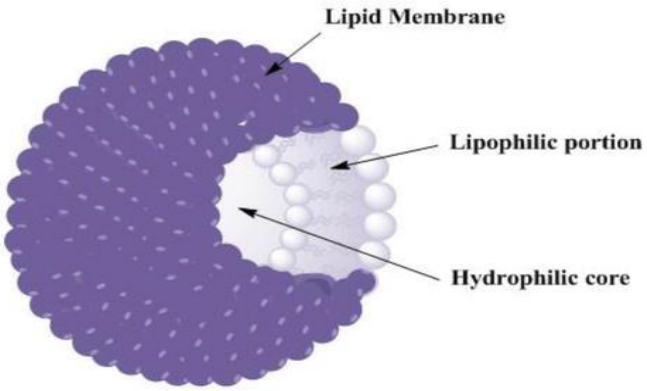

Figure 3*: *Inner and outer structure of liposome

Methods of Preparation of Liposomes.

Active Loading Techniques

Mechanical Dispersion Method

Lipid film hydration by hand shaking, non-hand shaking, or freeze-drying.
Micro-emulsification.
Sonication.
French pressure cell.
Membrane extrusion.
Dried reconstituted vesicles.
Freeze-thawed liposomes.

Solvent Dispersion Method

Ethanol injection.
Ether injection.
Double emulsion.
Reverse phase evaporation vesicles.
Stable plurilamellar vesicles.

Passive Loading Techniques

Detergent Removal Method

Detergents (e.g., cholate alkyl glycoside, Triton X-100) removal from mixed micelles using:
Dialysis.
Column.
Chromatography.
Dilution.
Reconstituted Sendai virus envelopes.

Thin Film Hydration Method (Bangham Method)

This is one of the most popular and traditional methods for creating liposomes. The basic steps are: Lipid Dissolution: Methanol and chloroform are examples of organic solvents in which lipids dissolve. Formation of a Fine Lipids Film: The organic solvent is evaporated at a lower pressure using a rotary evaporator, leaving behind a monetary fine lipids film upon the flask walls. Hydration: When an aqueous buffer, like phosphate-buffered saline, or PBS, which is is added to the dried lipid film, multilamellar vesicles, or MLVs, are formed. Sonication or Extrusion: The MLVs are then subjected either to sonication or extrusion to reduce the size of the vesicles in order to produce tiny unilamellar vesicles (SUVs).

Dissolve Lipids in Organic Solvent
↓
Form Thin Lipid Film (Rotary Evaporation)
↓
Hydrate with Aqueous Buffer
↓
Formation of Multilamellar Vesicles (MLVs)
↓
Sonication or Extrusion (Optional)
↓
Small Unilamellar Vesicles (SUVs) [24]

Reverse-Phase Evaporation Method (REV)

Water-soluble medications can be effectively encapsulated using this technique. The fundamental actions consist of: The process of creating a water-in-oil emulsion involves dissolving lipids in an organic solvent, typically ether or isopropyl ether, and then using sonication to emulsify an aqueous phase that contains the medication in the lipid solution. Solvent Removal: When the emulsion turns into an aqueous suspension, the organic solvent is extracted under vacuum, forming large unilamellar vesicles (LUVs).

Reverse-Phase Evaporation Method (REV)

Dissolve Lipids in Organic Solvent
↓
Add Aqueous Phase (Drug Solution) to Form Water-in-Oil Emulsion
↓
Sonication of Emulsion
↓
Remove Organic Solvent (Under Vacuum)
↓
Formation of Large Unilamellar Vesicles (LUVs) [25]

Formation of Liposomes By Using Solvents as an injection

Ethanol and ether injection are the two categories of solvent injection techniques. Ethanol Injection: Aqueous solutions are quickly injected with lipids that have been dissolved in ethanol. Rapid ethanol dispersion causes liposomes to develop on their own. Ether Injection: Aqueous phase that is kept at a temperature higher than ether's boiling point is injected with lipids that have been dissolved in ether. When ether comes into contact with the aqueous phase, it evaporates, forming liposomes.

Solvent Injection Methods (Ethanol & Ether Injection)

Ethanol Injection

Dissolve Lipids in Ethanol
↓
Inject Lipid Solution into Aqueous Phase
↓
Rapid Dispersion of Ethanol
↓
Spontaneous Formation of Liposomes

Ether Injection

Dissolve Lipids in Ether
↓
Inject into Heated Aqueous Phase
↓
Ether Evaporates
↓
Formation of Liposomes [26]

Detergent Removal Method (Dialysis Method)

Using a solution of water containing a detergent (such as Triton X-100), lipids are dissolved using this approach. By gradually removing the detergent, either through gel chromatography or dialysis, the lipids self-assemble into liposomes.

Step 1: The first step is to prepare the lipid-detergent solution.

Step 2: Detergent is removed slowly by dialysis, leading to the formation of liposomes.

Step 3: The liposomes formed are usually unilamellar.

Dissolve Lipids in Ether
↓
Inject into Heated Aqueous Phase
↓
Ether Evaporates
↓
Formation of Liposomes [27]

Microfluidic Method

Recent developments have resulted in the creation of liposome preparation methods using microfluidic technology. With this approach, you can: Aqueous Phase and Lipid Mixing: In microfluidic channels, lipid dissolved in a solvent that is organic are combined with an aqueous solution. Rapid Lipid Self-Assembly: As the organic solvent and aqueous phase mix, lipids spontaneously form bilayers and liposomes.

Dissolve Lipids in Organic Solvent
↓
Inject into Aqueous Phase in Microfluidic Channel
↓
Rapid Lipid Self-Assembly
↓
Formation of Liposomes [28]

Freeze-Thaw Method

This approach is frequently employed for enhancing the effectiveness of the encapsulation of aqueous pharmaceuticals. The steps are as follows. MLV formation: Thin-film hydration is used to prepare liposomes. Freeze-thaw Patterns: The liposome suspension is frozen (e.g., in liquid nitrogen) & thawed (e.g., at a room temperature or 37°C), causing bilayer fusion and rearrangement, resulting in more homogeneous liposomes.

Prepare Multilamellar Vesicles (MLVs)
↓
Freeze (e.g., Liquid Nitrogen)
↓
Thaw (e.g., Room Temperature or 37°C)
↓
Repeat Freeze-Thaw Cycles
↓
Formation of Homogeneous Liposomes [29]

Dehydration-Rehydration Vesicles (DRV) Method

This method involves:

Formation of Small Vesicles

Initially, small unilamellar vesicles (SUVs) are formed by sonication or extrusion.

Dehydration: Next, the vesicles are dried using a technique like freeze-drying. Upon rehydrating the dehydrated vesicles, bigger, multilamellar vesicles with enhanced encapsulation efficiency are formed.

Prepare Small Unilamellar Vesicles (SUVs)
↓
Dehydrate (Freeze-Drying)
↓
Rehydrate with Aqueous Solution
↓
Formation of Larger, Multilamellar Vesicles [30]

Evaluation Parameters of Liposomes

Different production methods provide different physicochemical properties, which may have an impact on how well they function both in vivo (such as biodistribution) and in vitro (such as stability and sterilizing). Therefore, to ensure consistent in vitro and in vivo action with the liposomal medicinal product, it is essential to evaluate liposomes after formulation and during storage using quick, accurate, and reproducible quality control processes.

Size and Size Distribution

When liposomes are meant to be inhaled or administered parenterally, distribution of sizes is a crucial consideration. The ejection of encapsulated medications and the mechanism of action of liposomes are both greatly impacted. Liposomal vesicle size is determined using a variety of techniques.

These include optical microscopy, cryo-TEM, negatively stained transmitted electron microscopy (TEM), scanning electron microscopy (SEM), and freeze-fracture electron microscopy. Other commonly used diffraction and scattering techniques include laser light scattering and photon correlation spectroscopy (PCS). Other methods, like hydrodynamic techniques (e.g., Gel Permeation Chromatography, taken Ultracentrifugation, and Field Stream Fractionation), are also used to examine the size and dispersion of liposomes.

Zeta Potential

Zeta potential, a measurement of surface charge, affects liposomes as' physical stability and ability to communicate with biological membranes. Better stability is correlated with higher absolute values. [31]

Encapsulation Efficiency

Estimating the amount of medication retained within liposomes depends on encapsulation efficiency. Usually, techniques like gel filtration or ultracentrifugation are used to evaluate it. [32]

Drug Release Profile

In vitro drug release studies evaluate how quickly the drug is released from liposomes, which is essential for predicting in vivo behavior. [33]

Stability Testing

Stability studies assess liposomal integrity and drug content over time, determining the impact of various storage conditions on product stability.

Surface Morphology

Liposomes' relationships with biological systems are influenced by their surface shape. Liposome surfaces are seen and characterized using methods such as SEM and AFM. [34]

Applications of Liposomes

Liposomes are adaptable drug delivery vehicles that have been used in many different industries, most notably biotechnology and pharmaceuticals. They are appropriate for a variety of therapeutic applications due to their special qualities, which include biocompatibility, the capacity to encompass both hydrophilic and hydrophobic medications, and controlled release characteristics. The following are some important uses for liposomes:

Drug Delivery Systems

Targeted Drug Delivery: By being designed to specifically target particular tissues or cells, liposomes can increase therapeutic efficacy while lowering negative effects. It is possible to obtain targeted distribution towards cancerous cells or other disease areas by altering the liposome surface with ligands or antibodies.

Example

Liposomal doxorubicin (Doxil) is designed for targeted delivery to tumor cells, reducing systemic toxicity compared to free doxorubicin.

Controlled Release

Liposomes can provide sustained release of drugs, allowing for lower dosing frequency and improved patient compliance. This is particularly beneficial for chronic diseases where long-term treatment is necessary.

Example

Long-acting liposomal formulations of antibiotics can maintain effective drug levels over extended periods, enhancing treatment effectiveness and patient adherence. [35]

Vaccines

Vaccine Delivery: Liposomes serve as adjuvants and delivery vehicles for vaccines, enhancing immune responses by delivering antigens more effectively. Their ability to mimic biological membranes allows for better uptake by antigen-presenting cells.

Example

Liposomal vaccines, such as those developed for tuberculosis, improve immunogenicity and stability of the antigen, leading to stronger immune responses.

Gene Therapy

Nucleic Acid Delivery

DNA, RNA, and siRNA are nucleic acids that liposomes can encapsulate for use in gene therapy. They provide efficient gene delivery by shielding nucleic acids from deterioration and promoting cellular absorption.

Example

Liposomal formulations containing siRNA have been used to silence specific genes involved in cancer progression, demonstrating potential in cancer treatment. [36]

Cosmetic and Dermatological Applications

Skin Delivery Systems

Liposomes improve the way active chemicals are delivered in dermatological and cosmetic treatments. The efficacy of topical therapies is increased by their capacity to transport hydrophilic and lipophilic molecules through the epidermal barrier.

Example

Liposomal formulations of retinol and vitamins in skincare products enhance skin absorption, improving their therapeutic effects against aging and skin disorders.

Diagnostics and Imaging

Contrast Agents for Imaging

Liposomes can be loaded with imaging agents for use in diagnostic procedures. They are perfect for enhancing the distinction of imaging modalities like MRI and ultrasound because of their biocompatibility and capacity to encapsulate different agents.

Example

Liposomal formulations containing gadolinium-based contrast agents enhance MRI imaging quality and provide better visualization of tissues. [37]

Treatment of Infectious Diseases

Antimicrobial Delivery: Liposomes are used to deliver antifungal, antibacterial, and antiviral agents, improving their bioavailability and therapeutic efficacy while reducing toxicity.

Cancer Therapy

Chemotherapy

By encapsulating chemotherapy medicines, liposomes may minimize systemic exposure and related negative effects while enabling specific administration to tumor locations.[38]

Anti-Inflammatory Applications

The treatment of inflammatory diseases can be improved while reducing systemic side effects by using liposomes to encapsulate anti-inflammatory medications for precise administration to inflammatory tissues.

Example

Liposomal formulations of corticosteroids can be directed to inflamed areas in conditions such as rheumatoid arthritis, providing localized therapy with reduced systemic exposure. [39]

Marketed Product	Drug Used	Target Diseases	Company
Alec™	Dry protein-free powder of DPPC PG	Expanding lung diseases in babies	Britannia Pharm, UK
Ventus™	Prostaglandin E1	Systemic inflammatory diseases	The Liposome Company, USA
Topex Br	Terbutaline sulphate	Asthma ozone	USA
Doxil™ or Caelyx™	Doxorubicin	Kaposi's sarcoma	SEQUUS, USA
Novasome	Smallpox vaccine	Smallpox	Novavax, USA
Evacet™	Doxorubicin	Metastatic breast cancer	The Liposome Company, USA
Fungizone®	Amphotericin B	Fungal infections, leishmaniasis	
Depocyt	Cytarabine	Cancer therapy	Skye Pharm, USA
Doxil®	Doxorubicin HCl	Refractory ovarian cancer	ALZA, USA
Amphotec™	Amphotericin	B fungal infections, leishmaniasis	SEQUUS, USA

Table 1*: *Marketed Liposomes formulations

Product	Manufacturer	Lipsosomes and Key Ingredients
Formule Liposome Gel	Formule Liposome Gel Payot (Ferdinand Muehlens)	(Thymoxin) hyaluronic acid
Symphatic 2000	Biopharm GmbH	Thymus extract vitamin A palmitate
Niosomes	Lancome (L'Oréal)	Glyceropolyether with moisturizers
Inovita	Pharm/Apotheke	Thymus extract, hyaluronic
Future Perfect Skin Gel	Estee Lauder	TMF, Vitamins E, A palmitate, cerebroside ceramide
Flawless Finish	Elizabeth Arden	Liquid makeup
Eye Perfector	Avon	Soothing cream to reduce eye
Nactosomes	Lancome (L'Oréal)	Vitamins
Effect du Soleil	L'Oréal	Tanning agents in liposomes niosomes Lancome
Natipide II	Nattermann PL	Liposomal gel for do-it-yourself

Table 2*: *Liposomal cosmetics formulations

CONCLUSION

The investigation of innovative liposome-based herbal medication delivery systems marks a substantial breakthrough in both herbal medicine and pharmaceutical technology. Liposomes are a useful tool for improving the stability, controlled release, and bioavailability of herbal ingredients, resolving frequent issues with conventional herbal formulations. Liposomes' capacity to wrap up the hydrophilic and hydrophobic substances opens up a wider range of herbal uses by reducing side effects and enabling the transportation of bioactive substances to specific bodily locations.

Moreover, the customization of liposome formulations through surface modifications and targeted ligand attachment opens new avenues for personalized medicine, allowing for the optimization of therapeutic outcomes in individual patients. The incorporation of herbal extracts into liposomal systems not only preserves the therapeutic properties of the phytochemicals but also enhances their pharmacokinetic profiles, potentially leading to improved efficacy in treating various health conditions.

Stressing the significance of thorough scientific proof and standardized production techniques is essential as this field of study develops in order to guarantee the efficacy and safety of herbal liposomal compositions. Future studies should focus on long-term stability assessments, in vivo efficacy testing, and clinical trials to fully realize the potential of herbal liposomes in modern therapeutics.

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