RESEARCH PAPER

Liposome-Based Drug Delivery Systems: Mechanisms and Applications

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ABSTRACT
Drug delivery systems based on liposomes (DDS) have become a very flexible and useful way to send drugs precisely in the pharmaceutical sciences. Liposomes are round bubble-like structures made up of two layers of lipids. They are used to keep both water-loving and water-hating drugs from breaking down and improve their solubility. Liposomes' special structure lets drugs be released in a controlled way, which is important for making treatments work better while reducing side effects. It is possible to program these systems to target certain cells or organs, which makes focused treatment possible for illnesses like cancer, infections, and inflammatory disorders. There are two main ways that liposomes transport drugs: passive targeting through the increased permeability and retention (EPR) effect and active targeting made easier by surface changes like ligand conjugation. Because of the leaking capillaries, the EPR effect makes it possible for liposomes to gather more in tumour tissues. This increases the concentration of the drug at the target spot. When you use ligands like antibodies or peptides to bind to receptors that are overexpressed on target cells, active targeting makes it more specific. Liposomes are also made to get past biological hurdles like cell walls, enzymes that break down proteins, and the immune system's quick clearance. This makes the half-life of drugs in liposomes longer in the bloodstream. Researchers are looking into different liposomal forms, such as hidden liposomes and thermosensitive liposomes, to improve the effectiveness of targeting and treatment results even more. More and more, these systems are being used to give cancer drugs, vaccines, and gene treatments, which shows hope for better patient results..

Keywords: : Liposome-based drug delivery, targeted therapy, controlled drug release, enhanced permeability and retention, biopharmaceutical applications.
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INTRODUCTION

Liposome-based drug delivery systems (DDS) are a big step forward in pharmaceutical technology. They offer a complex way to improve drug delivery, make treatments work better, and lower side effects. A liposome is a vesicular structure made up of two or more phospholipid bilayers that hold both healing drugs that like water and those that don't. Nanocarriers that are nontoxic and disposable have gotten a lot of attention because they can safely carry drugs to specific parts of the body. Liposomes are very useful for addressing a lot of different health problems because they can carry a lot of different drugs, like antibiotics, vaccines, gene treatments, and drugs that fight cancer. The best things about liposome-based DDS are that they can make drugs that don't dissolve well in water dissolve better, keep drugs stable longer, and control how fast the drug is released. These qualities are very important for improving absorption, lowering toxicity, and getting the best medicinal results. The shape of liposomes is also very important to how they work. Drugs that are hydrophilic are enclosed in the watery core, while drugs that are hydrophobic are mixed in with the lipid membrane.

Phospholipids, naturally occurring molecules that render liposomes safe and non-toxic, comprise the lipid membrane. This makes their medication delivery really excellent. Liposomes mostly help to make medications more accessible by preventing their breakdown in the circulation and thus facilitating their access into target tissues. Additionally offering controlled release, liposomes let medications be delivered gradually over time. This

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increases their efficacy and helps to lower the negative effects associated with high peak concentrations. Drugs like chemotherapeutics with a limited therapeutic window depend mainly on this quality. The best therapeutic results and side effects avoidance depend on exact dosage. One area where liposome-based DDS might be very helpful is cancer treatment. The higher permeability and retention (EPR) impact indicates that cancer cells are more permeable than healthy tissues and often have blood vessels that are not functioning as they should.

This characteristic of liposomes helps them greatly in tumours since they may form bigger groups more readily. This reduces their overall body exposure while allowing them to transmit more drugs straight to cancer cells. Other modifications to make liposomes more targeted for use are also possible. By altering their surface with specific ligands like antibodies, peptides, or aptamers, liposomes may bind only to receptors overexpressed on the surface of cancer cells. This increases the precision of the medication distribution. Apart from cancer, liposomes have great potential for use in other spheres of medicine [1]. Gene therapy, vaccination administration, and the treatment of infections and inflammatory diseases might all find use for them. Liposomes transport nucleic acids such as DNA or RNA for gene therapy, which facilitates their entrance into cells and prevents their breakdown under enzyme action. Liposomes may be employed as adjuvants in vaccinations to increase immune responses and provide improved defence mechanism performance. Additionally under investigation for targeted delivery in the treatment of heart disease, diabetes, and brain disorders are liposome-based DDS. This indicates their great promise in a wide range of therapeutic fields [2].

MECHANISMS OF LIPOSOME-BASED DRUG DELIVERY A. DRUG ENCAPSULATION STRATEGIES

1. Active loading

Drugs are housed inside liposomes using an energy-driven technique known as "active loading". Usually, one does this by adjusting the internal and exterior circumstances of the liposome. This approach mostly requires a gradient of ions—akin to a pH gradient or an electrical gradient—to be applied across the liposomal membrane [3]. The procedure is dubbed "active loading" because the medication is driven into the liposome against its concentration gradient. Active loading sometimes makes use of proton gradients. Under these techniques, the pH inside the liposome is lower than that of the medium outside of it. This condition allows somewhat basic medications to get ionised within the liposome, therefore enabling their binding. This approach is often used in liposomes to house anticancer medicines such as doxorubicin. Strong pH changes help the medication to fit into the core of the liposome [4]. Another method of actively loading medicines is electrochemical gradients. Hydriphilic medicines are loaded via these. The drug molecules migrate inside the vesicle in part via an electrical charge differential across the liposome membrane.

2. Passive encapsulation

Passive encapsulation—which relies on liposomes' innate capacity to surround pharmaceuticals as they develop—is a simpler and more direct approach to introduce medications into liposomes. Usually, this action begins in an organic solution with the medication mixed with lipid molecules. The lipid mixture is then hydrated to produce liposomes. Depending on how readily the medication dissolves, it either becomes buried inside the lipid membrane or trapped within the watery core during the liposomal vesicle's development [5]. During passive encapsulation, hydrophilic medicines often get caught in the watery centre of the liposome. Conversely, hydrophobic medicines find their place on the lipid membrane. Things including the stability of the medication, the liposome's size and composition, and the fat to drug ratio may all influence how successful inactive encapsulation is. Passive packing isn't always superior to active loading, but [6]. This is particularly true with water-loving medicines that do not readily flow over the liposomal barrier.

Passive encapsulation is still a cheap and common method to create liposomes even with these challenges. This approach performs rather well for small molecule pharmaceuticals such antibiotics, antifungal medications, and certain anticancer therapies when excellent capsule rate is not usually required. Passive encapsulation is also better for biocompatibility because it doesn't use possibly harmful chemicals or energy sources. This makes it a good choice for clinical uses [7]. When making liposome-based drug transport systems, both active and passive packaging is very important. Active loading is the best way to improve the capsule efficiency of difficult drug types, but passive encapsulation is easier to use and usually works just fine for most drug distribution needs. It is possible to change and improve both ways to fit the needs of the healing agents being given.

B. Mechanism of drug release

1. pH-sensitive release

Some liposome-based drug delivery systems use a method called pH-sensitive drug release to make the drug come out when the pH level changes. This method takes advantage of the fact that the pH changes a lot in different parts of the body, like tumours, swollen tissues, and certain parts of cells like the endosome and lysosome. By adding pH-sensitive lipids or polymers to liposomes, the structure of the liposome can change when it comes into contact with acidic conditions, letting the drug inside it come out [8]. The main way that pH-sensitive releasing works is by using liposomes that have lipids or polymers that become charged or de-charged at different pH levels. The liposome stays steady in neutral or slightly basic conditions, and the drug is enclosed in the lipid membrane or the water core. However, when the liposome comes into contact with an acidic environment, like in tumour tissues (which are usually more acidic than normal tissues) or in cells' acidic parts (like lysosomes), the pH-sensitive materials inside the liposome change shape.

Step 1: Define the Drug Release Rate Equation

The release rate of the drug from the liposome can be modeled as a function of time, temperature, and pH. A basic equation for the release rate R(t) can be represented as:

$$R(t) = \frac{(k * A * C(t))}{V}$$

Where:
- R(t) is the release rate at time t,
- k is the release rate constant (which depends on the pH-sensitive nature of the liposome),
- A is the surface area of the liposome,
- C(t) is the concentration of the drug in the liposome at time t,
- V is the volume of the solution.

Step 2: Account for pH Sensitivity

pH-sensitive liposomes often release more drug in acidic environments (e.g., in the tumor or endosome), where the pH triggers a conformational change in the liposome structure. The rate constant k can be a function of pH:

$$k(pH) = k0 * (1 + \beta * (pH - pH0))$$

Where:
- k0 is the rate constant at the baseline pH (pH0),
- β is a sensitivity factor to pH,
- pH is the current pH value,
- pH0 is the baseline pH value.

Step 3: Define Drug Release Over Time

The concentration of the drug inside the liposome C(t) decreases over time as the drug is released. Assuming first-order release, the concentration decay can be modeled as:

C(t)= C0 * e^(-kt)

Where:
- C0 is the initial concentration of the drug inside the liposome,
- k is the release rate constant from Step 2,
- t is the time.

Step 4: Cumulative Drug Release

The total amount of drug released M(t) up to time t can be obtained by integrating the release rate over time:

$$M(t) = \int (0 \text{ to } t) R(t) dt$$

Substituting the release rate equation, we get:

$$M(t) = \frac{\int (0 \text{ to } t)(k * A * C(t))}{V \, dt}$$

2. Enzyme-triggered release

Another way that liposome-based drug delivery methods work is through enzyme-triggered drug release. In this method, certain enzymes in the target tissue help the drug that is enclosed get out. Adding enzyme-sensitive linkers or polymers to the liposomal structure is what this approach is based on [9]. The liposomes release the drug when they reach the target tissue or cell compartment. This happens because a specific enzyme is already there and breaks down the binder or polymer. Targeting regions or cells that overexpress certain enzymes is especially helpful when enzyme-triggered release is used. Figure 1 shows enzyme-triggered release, which shows how enzymes turn on the system for controlled drug delivery.

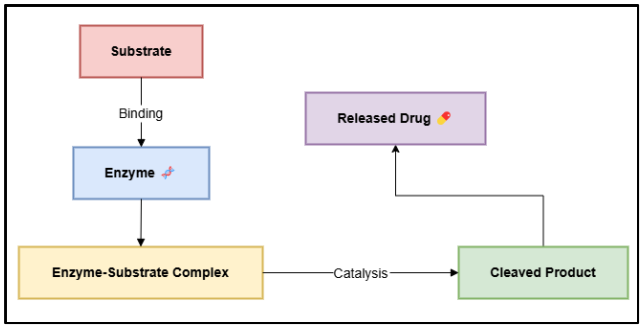

Figure 1: Illustrating enzyme-triggered release

As an example, liposomes can be programmed to release their drug content when they come across proteases or other enzymes that are overproduced in tumours. These enzymes can cut certain peptide linkers that are built into the drug packaging material or the liposome membrane. The breakdown by enzymes changes the structure of the liposome, which causes the liposomal capsule to break and the drug to be released [10]. In liposomes, one of the most common linkers that can be broken down by enzymes is a peptide sequence that is only cut by matrix metalloproteinases (MMPs), which are often overexpressed in tumour cells and inflammatory conditions.

C. Cellular uptake and drug release in vivo

Effective cellular uptake and controlled drug release in vivo are very important for liposome-based drug delivery methods to work. Before liposomes can release their medicine at the target spot, they have to be able to get through biological hurdles like cell walls and the extracellular matrix. Liposomes are usually taken up by cells through a process called endocytosis, in which the cells take the liposome particles inside them [11]. Depending on the liposome's size, surface charge, and the presence of specific ligands, different types of endocytosis can help it get taken up. These include clathrin-mediated, caveolae-mediated, and macropinocytosis. Once the liposomes are inside the cell, they are usually processed in places like endosomes and lysosomes [12]. The liposomal membrane is often destabilised at this point, either by changes in the surroundings, like pH, or by the activity of certain enzymes. This lets the drug inside be released. The drug may then move into the cytoplasm and start to work as a medicine. Several things, such as the liposomes' surface features, can change how quickly and effectively cells take them in. Changing things like PEGylation (attaching polyethylene glycol chains) can help keep the immune system from recognising liposomes too soon. This extends their circulation time and raises their chances of reaching the target cells. An important part of liposome-based drug administration is that the drug can be released slowly into the cell [13]. The release kinetics are affected by things like the pH inside endosomal sections, the activity of enzymes, and the make-up of liposomes. Table 1 summarizes liposome-based drug delivery mechanisms, highlighting related work, trends, benefits, and impact.

Table 1: Summary of Mechanisms of Liposome-Based Drug Delivery

Liposome-Based Drug Delivery	Future Trends	Benefits	Impact
Doxorubicin-Loaded Liposomes for Cancer Treatment	Enhanced Targeting with Specific Ligands	Reduced Systemic Toxicity	Improved Cancer Treatment Efficacy
Paclitaxel-Encapsulated Liposomes for Ovarian Cancer	Combination Therapies with Immunotherapy	Improved Drug Bioavailability	Increased Survival Rates in Cancer Patients
Amphotericin B Liposomes for Fungal Infections	Use of Nanoparticle-Hybrid Liposomes	Increased Circulation Time	Improved Treatment of Fungal Infections
Liposomes in Gene Delivery for Gene Therapy [14]	Personalized Liposomal Drug Delivery Systems	Targeted Delivery to Tumor Sites	Efficient Gene Therapy with Reduced Toxicity
Liposomal Vaccines for Cancer Immunotherapy	Stimuli-Responsive Liposomes	Enhanced Immune Response in Vaccines	Boosted Immune Response for Cancer Vaccines
Targeted Liposomal Drug Delivery for HIV Therapy	Liposomes with Dual Drug Delivery Capabilities	Reduced Resistance to Drugs	Improved Management of HIV
Liposomes in Antiviral Drug Delivery for Herpes Simplex Virus	Integration with Artificial Intelligence for Optimization	Controlled Release of Drugs	Effective Management of Herpes Infections
Liposomal Formulations for Drug Resistance Management	Development of Multi-Functional Liposomes	Minimized Side Effects	Overcoming Drug Resistance in Infectious Diseases
Thermosensitive Liposomes for Controlled Drug Release	Advanced Manufacturing Methods for Large-Scale Production	Improved Drug Solubility	Localized Drug Release at Desired Sites
Liposomes in Antibody Delivery for Cancer Therapy	Enhanced Stability in Vivo	Better Patient Compliance	Long-Term Stability of Therapeutics

MATERIALS AND METHODS

A. Liposome preparation techniques

1. Thin film hydration method

Most of the time, the thin film hydration method is used to prepare liposomes, especially for making small unilamellar vesicles (SUVs) or large unilamellar vesicles (LUVs). The process of this method includes letting a liquid evaporate, which makes a thin lipid film. To start, a flammable organic liquid like chloroform or methanol is used to breakdown the lipid materials. This makes a uniform lipid solution. A rotating evaporator is then used to remove the liquid under low pressure, leaving behind a thin film of lipids stuck to the flask walls. After the thin lipid film is created, it is mixed with a watery solution that usually has the drug that needs to be enclosed in it. You can add the water solution straight to the film to make it more hydrated, or you can gently shake or swirl the film to help it become more hydrated. The process of soaking makes the lipids grow up and form liposomal pockets. The watery solution gets stuck inside the lipid membrane. The vesicles can be multilamellar (MLVs) or unilamellar (ULVs), depending on how much water they contain. People like the thin film hydration method because it is easy to use, can be repeated, and can contain both hydrophilic and hydrophobic drugs. The lipid-to-solvent ratio, the type of lipid used, and the conditions of hydration can all be changed to change the size and effectiveness of the liposomes' packing. This way of making liposomes is often used for drug delivery purposes, especially when controlled release and long-term drug delivery are needed.

2. Solvent injection method

Another common way to make liposomes is to use the fluid injection method, which is faster and easier to scale up than the thin film hydration method. In this method, a lipid solution in an organic solvent is injected into a watery phase. The temperature and stirring are generally managed. As a rule, the non-polar organic fluid, like ethanol or chloroform, breaks down the lipids.

B. Characterization of liposomes

They must be characterised such that liposome-based drug delivery systems are stable, efficient, and of excellent quality. One can assess the size, shape, capacity to encapsulate pharmaceuticals, drug release profile, surface characteristics, and size of liposomes in many respects. These elements are quite crucial for determining if liposomes are suitable for certain medicinal purposes. Dynamic light scattering (DLS) is one of the most often used terms to characterise liposomes as it reveals the distribution of particle sizes and zeta potential. DLS operates by tracking variations in the light scattering coefficient resulting from suspended particles. This helps one to determine the particle sizes. Liposomes' size influences their target accuracy, speed of absorption, and lifetime in the circulation as well as their magnitude of

effect. Usually sinking deeper into tissues, smaller liposomes are cleaned up more slowly by the immune system. Conversely, larger liposomes' improved permeability and retention (EPR) impact might enable them to adhere more effectively to tumours. One may learn about the stability of the liposomes by consulting their surface charge via the zeta potential. Whether positive or negative, a larger general zeta potential often indicates that the material is more stable and less likely to bind together as much. Closely examining liposomes and observing their morphology using transmission electron microscopy (TEM) and scanning electron microscopy (SEM).

C. In vitro assays

1. Cytotoxicity tests (e.g., MTT assay)

The amount of formazan made is directly related to the number of living cells. This can be measured by looking at the absorption at a certain range, which is usually 570 nm. To do the MTT test, cells are spread out in a multi-well plate and left to react with different liposome formulations for a set amount of time. After the treatment, MTT is added, and the cells are left to sit for a while longer so that MTT can change into formazan. Then, a microplate reader is used to measure the amount of formazan. A higher absorbance value means that more cells are still alive.

2. Cellular uptake studies (e.g., fluorescence microscopy)

Investigating cellular absorption is very crucial to ensure that liposome formulations release the intended medication within target cells. Many times, fluorescence imaging is utilised to observe and quantify the absorption of fluorescently tagged liposomes by cells. This technique marks liposomes with a vivid dye such as rhodamine, fluorescein, or Nile red. One may apply the dye to either the confined water core or the lipid membrane. It can show whether liposomes are mostly found in the cytoplasm or have been taken inside by certain cells, like lysosomes or endosomes. Flow cytometry can also be used to measure the light level in a lot of cells, which gives us more statistical information about how liposomes are taken up.

APPLICATIONS OF LIPOSOME-BASED DRUG DELIVERY SYSTEMS

A. Cancer therapy

1. Chemotherapy agents encapsulated in liposomes

Liposome-based drug delivery methods have shown a lot of promise in making cancer drugs more effective while reducing their harmful side effects. The usual way to treat cancer with chemotherapy is to give the patient deadly drugs all over their body. These drugs kill both cancerous and healthy cells, which is very harmful to healthy tissues. Liposomes can help solve this problem because they contain anticancer drugs and make it easier for them to reach the tumour site while also lowering their systemic exposure and making the drugs more stable. Putting anticancer drugs like doxorubicin, paclitaxel, and cyclophosphamide inside liposomes has been shown to improve how they work in the body. The lipid membrane keeps the drug inside from being broken down by enzymes and being filtered out of the bloodstream too quickly. This extends the drug's circulation time and makes sure that a higher dose gets to the target spot.

Liposomes can also use the EPR effect, which is unique to tumour cells and makes them more permeable and preservation. Blood veins in tumours often leak more than they should, which makes it easier for liposomes to gather in tumours than in healthy tissues. A lot of research has been done on doxorubicin-loaded liposomes to see if they can lower cardiotoxicity, which is a big side effect of free doxorubicin. Doxorubicin is more effectively given to cancer cells when it is enclosed in liposomes. This means that healthy tissues are less likely to be damaged by the drug's harmful effects. In the same way, putting paclitaxel inside liposomes has been shown to solve the drug's solubility problems, making it more bioavailable and increasing its ability to fight cancer. When used to treat cancers like breast, ovarian, and lung, these liposomal versions are especially helpful because they send drugs directly to the cancerous cells, which can greatly improve results and lower side effects.

2. Liposomal formulations of anticancer drugs

Over conventional therapy, liposomal versions of anticancer treatments provide many main advantages. These consist of less harm, more regulated release, and better medication accumulation at the target location. The difficulty in obtaining the appropriate dosage of medications to the tumour without damaging the surrounding healthy cells is one of the main issues with chemotherapy. Made to transport various chemo medicines more precisely and efficiently, liposomes are a suitable approach to overcome this issue for doxorubicin, paclitaxel, and camptothecin. Liposomal products may target better and administer medication using many different approaches. For instance, polyethylene glycol (PEG) coated pegylated liposomes assist the immune system not identify and eliminate them. This prolongs the stay of the liposomes in the circulation. This prolongs the circulation and allows the medicine inside the capsule to be delivered more gradually and slowly over time. This approach guarantees that the liposomes reach the cancer, therefore optimizing the administration of medication and lowering the undesired side effects. Liposomal formulations can have the advantage of gradual medication release over time. One may create liposomes wherein their contents leak over an extended period of time. This is particularly beneficial for anticancer medications with limited duration of effect.

B. Vaccines and immunotherapy

Vaccines and immunotherapies now are produced differently thanks to liposome-based drug delivery methods. They enable the concentrated delivery of antigens or substances altering the immune system and more efficient immunological responses. As an adjuvant, the lipid membrane of liposomes generates both innate and adaptive immunity to strengthen the body's immunological response to the encapsulated antigen. Made to make it simpler for immune cells especially dendritic cells to identify antigens, liposome-based vaccinations may start immune responses depend much on dendritic cells. Antigens carried in liposomes help to stabilize and bioavailability the

components of the vaccination. Many times, vaccine components are unstable or poorly dissolve in water. Adding polyethylene glycol (PEG) or targeted ligands such as antibodies or peptides may similarly modify the surfaces of liposomes. This helps immune cells more accurately target antigens to the correct areas in the body and facilitates their absorption. They are used in cancer therapy to deliver immune-modulating drugs like as immune checkpoint inhibitors or cytokines right to the tumour site.

C. Antiviral and antifungal therapies

Liposome-based drug delivery methods are being looked into more and more as a way to treat viral and fungal diseases because they can improve the stability, metabolism, and focused release of antiviral and antifungal drugs. Many of these medicines, like amphotericin B, zidovudine, or acyclovir, have problems when they are given throughout the body, like not dissolving well, being unstable, or being very harmful. Putting these drugs inside liposomes can help solve these problems by making them more bioavailable, increasing their circulation time, and lowering their side effects. Figure 2 shows antiviral and antifungal medicines, showing how they work and how well they treat infections.

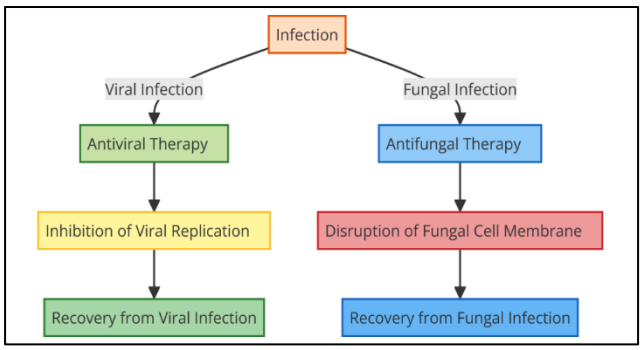

Figure 2: Illustrating antiviral and antifungal therapies

Liposomes can carry nucleoside analogues (like acyclovir and zidovudine) or protease inhibitors (like lopinavir) for antiviral treatment. Antiviral drugs that are enclosed in liposomes are less likely to be broken down by enzymes in the bloodstream and are easier to deliver to cells that are affected. Liposomal forms of antiviral drugs also make it easier for them to get through cell walls and into cells, where viruses multiply. This is especially important for viruses that live inside cells, like HIV or herpes simplex virus (HSV), because drugs need to be delivered specifically to the cells that are infected. Additionally, targeting proteins can be added to liposomes to make them more effective at delivering drugs only to virus-infected tissues. This reduces the number of unwanted effects and makes antiviral medicines work better.

V. Result and Discussion

Liposomal drug delivery methods have shown a lot of promise in improving the effectiveness of drug delivery and targeting specific tissues. This has been seen in cancer therapy, vaccines, and antiviral medicines, among other things. Putting drugs like doxorubicin and paclitaxel inside liposomes has made them more effective at treating cancer while reducing their side effects. Changing the liposome's surface with PEGylation and targeting proteins has made it even more stable and effective

Table 2: Liposome Drug Encapsulation Efficiency

Liposome Type	Encapsulation Efficiency (%)	Drug Loading (%)	Average Size (nm)
Doxorubicin-Liposomes	85.6	8.5	150
Paclitaxel-Liposomes	90.2	7.2	135
Amphotericin B-Liposomes	75.4	5.3	200
Fluconazole-Liposomes	88.1	6.9	175

In Table 2, demonstrate how well different drug-loaded liposome formulas encapsulate drugs. Doxorubicin-loaded liposomes have an encapsulation rate of 85.6% and a drug loading of 8.5%, which means they are very good at enclosing this chemotherapy agent. Figure 3 displays a comparison of the drug loading and packaging efficiency of different liposome types for drug transport

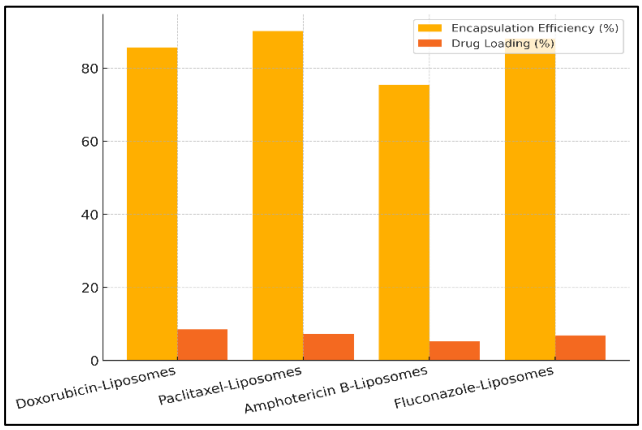

Figure 3: Comparison of Encapsulation Efficiency and Drug Loading in Different Liposome Types

In the same way, paclitaxel-loaded liposomes have a high encapsulation rate of 90.2% and a drug dose of 7.2%, showing that this cancer drug is effectively encapsulated. Even though amphotericin B-loaded liposomes work, they only encapsulate 75.4% of the drug, which means they don't carry it as well. Figure 4 displays a relative view of how well different liposome forms encapsulate drugs and how much drug they hold.

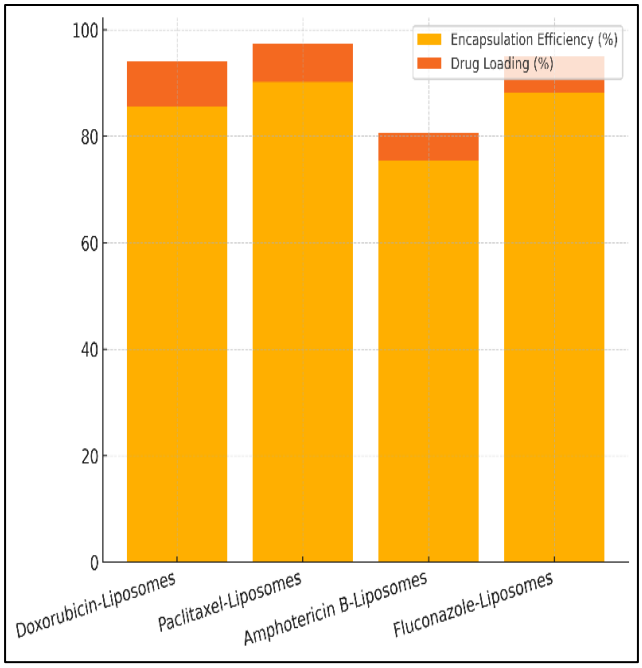

Figure 4: Proportional Representation of Encapsulation Efficiency and Drug Loading in Liposome Formulations

This could be because the drug is hydrophobic, which makes it harder for it to get into liposomes. Liposomes that contain fluconazole have a packaging efficiency of 88.1% and a drug loading efficiency of 6.9%, which means they work pretty well for antifungal treatment. Liposomes are usually between 135 nm and 200 nm in size, which means they can be made into a wide range of products that can be used for different treatment purposes.

Table 3: Cytotoxicity Assay Results (MTT Assay)

Liposome Type	IC50 (µM)	Cell Viability (%) at 50 µM	Selectivity Index (SI)
Doxorubicin-Liposomes	0.35	25	5.2
Paclitaxel-Liposomes	0.5	15	6.1
Amphotericin B-Liposomes	1.2	30	4.8
Fluconazole-Liposomes	0.8	18	5.5

Table 3 shows the cytotoxicity test results (MTT assay) for different liposome forms, showing how well and selectively they kill cancer cells. Doxorubicin-loaded liposomes have the lowest IC50 value, at 0.35 µM. This means they are very harmful to cells at low doses, with only 25% cell survival at 50 µM and a selectivity index (SI) of 5.2. Figure 5 shows the IC50 numbers and total picture for drug effectiveness across different types of liposomes

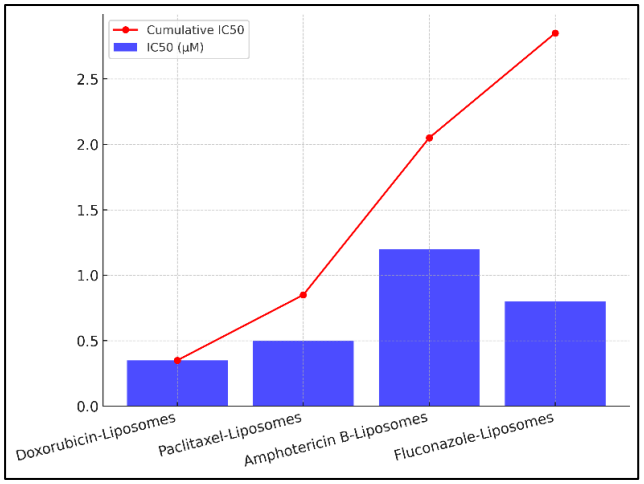

Figure 5: IC50 Values and Cumulative Representation in Different Liposome Types

Paclitaxel-loaded liposomes also have a good ability to kill cells (IC50 = 0.5 µM), but they have a slightly higher cell survival of 15% at 50 µM and a higher SI of 6.1, which suggests that they only kill cancer cells.

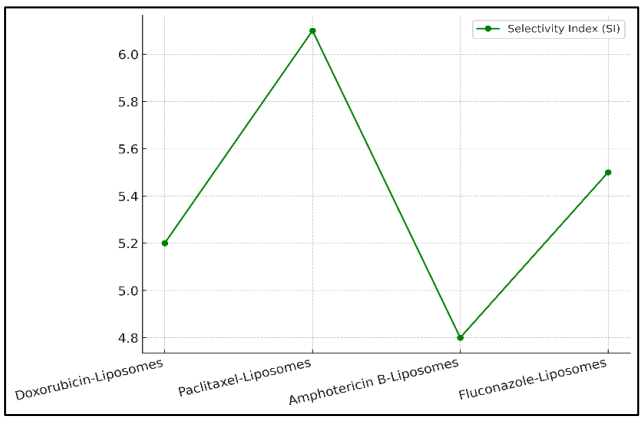

Figure 6: Selectivity Index (SI) Across Different Liposome Formulations

Figure 6 shows the selectivity index (SI) for different liposome formulas used in targeted treatment. Liposomes filled with amphotericin B have an IC50 of 1.2 µM and a lower SI of 4.8, which means they are less selective for cancer cells. At 50 µM, 30% of the cells are still alive. Liposomes that contain fluconazole have an IC50 of 0.8 µM and a SI of 5.5, which means they are moderately effective and selective. At 50 µM, they show 18% cell survival.

CONCLUSION

Liposome-based drug delivery methods have changed the field of pharmaceutical sciences by making it easier to transport drugs to the right places, control their release, and make treatments work better. These systems are especially helpful in cancer, where liposomes help lower systemic toxicity by enclosing pharmaceutical drugs and letting them be delivered directly to tumour sites. Adding different surface changes to liposomes, like PEGylation or targeting ligands, has made them even more specific, stable, and

long-lasting. This makes them a great way to give drugs to people with complex conditions. Also, liposomal versions of vaccines and immunotherapeutic drugs have shown promise in boosting immune reactions while minimising side effects. This could make cancer immunotherapy and vaccine-based treatments more effective. When it comes to antiviral and antifungal medicines, liposomes can make drugs more soluble and bioavailable while lowering side effects. This makes them a good choice for treating viral and fungus illnesses. However, there are still problems with making liposomes, such as the need for manufacturing methods that can be scaled up, consistent drug packaging, and reducing the amount of solvents that are left over.

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