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Review Article

The Role of Liposomes in Precision Oncology: A Review

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ABSTRACT

Cancer is a complex disease characterized by uncontrolled growth and proliferation of abnormal cells, often resulting from genetic mutations, environmental exposures, lifestyle factors, or infections. Conventional treatments, including surgery, chemotherapy, and radiation therapy, primarily target rapidly dividing cells but can inadvertently damage healthy tissues, cause significant side effects and limit their overall effectiveness. To address these challenges, nanoparticle-based drug delivery systems have emerged as a promising strategy to enhance therapeutic precision while minimizing harm to normal cells. Among these, liposomal nanomedicine utilizes small, spherical vesicles composed of phospholipid bilayers capable of encapsulating both hydrophilic and hydrophobic drugs. Liposomes exploit the unique properties of tumor vasculature, particularly the enhanced permeability and retention (EPR) effect, allowing selective accumulation in diseased tissues while reducing systemic exposure. Recent advances include surface modifications such as PEGylation, ligand-mediated active targeting, and stimuli-responsive designs that release drugs in response to pH, temperature, or enzymatic triggers. Liposomes are also being applied to deliver nucleic acid therapies, including siRNA and mRNA, broadening their therapeutic potential. Despite challenges such as immune system recognition, variable tumor uptake, and payload leakage, liposomal nanomedicine has matured into a versatile platform that bridges experimental nanotechnology with effective, safer, and more controlled cancer therapies.

INTRODUCTION

Cancer is defined as the uncontrolled growth and proliferation of abnormal cells within the body. The cells responsible for causing cancer are known as malignant cells, which possess the ability to divide without control, invade surrounding tissues, and spread to distant parts of the body through blood or lymphatic vessels a process known as metastasis. Unlike normal cells, which follow regulated cycles of growth, division, and programmed death (apoptosis), malignant cells

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lose these control mechanisms, allowing them to multiply indefinitely. The disease can affect virtually any tissue or organ, and its development is often gradual, beginning with minor mutations that accumulate over time until normal cellular functions are severely disrupted. The common types of cancer include Leukemia (cancer of blood-forming tissues), Brain Cancer, Liver Cancer, Colorectal Cancer, Lung Cancer, Thyroid Cancer, Hodgkin's and Non-Hodgkin's Lymphoma, Skin Cancer, and Kidney Cancer. Additionally, certain cancers are gender-specific due to hormonal and reproductive system differences Penile, Testicular, and Prostate Cancer are more prevalent in men, whereas Cervical, Uterine, Ovarian, and Breast Cancer are predominant in women. Among these, lung, breast, colorectal, prostate, and liver cancers collectively account for a majority of global cases and deaths. Cancer can also occur in children, where leukemia and brain tumors are among the most common pediatric malignancies. Globally, cancer is a major public health burden. While current data on global cancer incidence and mortality have not yet been published, estimates from 2022 report approximately 20 million new cases and 9.7 million deaths due to cancer worldwide. Among the most commonly diagnosed cancers in 2022 were lung cancer (~2.5 million new cases), female breast cancer (~2.3 million), colorectal cancer (~1.9 million), and prostate cancer (~1.5 million). The leading causes of cancer mortality globally are lung cancer (~1.8 million deaths in 2022), followed by colorectal, liver, stomach, and breast cancers. By 2050, new cancer cases are projected to reach around 35 million annually, representing about a 77% increase over 2022 numbers, and cancer-related deaths are expected to rise proportionally if current risk exposures and detection/treatment gaps persist. In India alone, in 2022, there were more than 1.41 million (14.1 lakh) new cancer cases, and over 910,000 (9.1 lakh) deaths due to cancer; breast cancer was the most common among women, while lip, oral cavity, lung among men, and breast and cervix among women were leading sites. Uncontrolled cell growth Caused by genetic mutations and damage in DNA, which disrupt normal regulatory mechanisms. These changes may result from inherited genetic factors, environmental exposures (like radiation, pollution, or chemicals), lifestyle choices (such as smoking, alcohol, and poor diet), infections (like HPV or hepatitis viruses), or aging-related errors in cell division. Together, these factors lead to abnormal cells evading the body's defense mechanisms, forming tumors, and in severe cases, spreading to other organs. Cancer treatment includes surgery, which removes the tumor; chemotherapy, using drugs to kill cancer cells; radiation therapy, which uses high-energy beams; immunotherapy, boosting the body's immune system to fight cancer; targeted drug therapy, focusing on specific cancer cell abnormalities; and hormone therapy, for hormone-fueled cancers. As Cancer Cells divides in much rapid rate than normal rate, all these Medication and treatments are designed to kill these rapid dividing cells but, in this process, Healthy Cells may also get Killed; But it is quite normal that some normal cells have faster rate of dividing thus making them a target to these Medication and Treatments. This Problem caused to find solution and thus Nanoparticle Drug delivery System was Introduced. Nanoparticle Drug Delivery System is modern methods that use nanoparticles for delivery and controlled Release of Drugs. Various Nanoparticles are used for Nanoparticle Drug Delivery like; Gold Nanoparticles, Platinum Nanoparticles, Dendrimers, Polymeric Nanoparticles, Range of Various Organic Nanoparticles & Liposomal Nanoparticles. Liposomal Nanoparticle Drug Delivery uses Liposome as carrier of drugs which is used to treat Various Diseases in instance of

Infections caused by Fungus and Bacteria, Cancer, menopausal Therapy and Hepatitis. Liposomes were first discovered by Alec D. Bangham in 1961 at the Babraham Institute in Cambridge, UK. While studying phospholipids under an electron microscope, he observed that these molecules spontaneously formed closed bilayer vesicles in water—what we now call liposomes. This discovery revolutionized targeted drug delivery research.

Cancer: Cancer is a generic term used group of disease caused by uncontrolled growth of cells. Cancer arises from the mutation in gene that cause misfunctioning of cell mainly in the gene that controls cell division and cell growth.

Cancer is fundamentally classified by site of origin of Cancer which acknowledged in table 1.

Table 1: Types of Cancer according to the site of Action:

1.Cell	1.Sarcoma
	2.Carcinoma
	3.Leukemia
	4.Lymphoma
	5.Melanoma
2.Organ	1.Brain Cancer
	2.Buccal Cancer
	3.Thyroid Cancer
	4.Lung Cancer
	5.Stomach Cancer
	6.Pancreatic Cancer
	7.Liver Cancer
	8.Kidney Cancer
	9.Cervical Cancer
	10.Penile Cancer
	11.Testicular Cancer
	12.Prostate Cancer
	13.Breast Cancer
	14.Uterine Cancer
	15.Hodgkin's Lymphoma
	16.Non-Hodgkin's Lymphoma
	17.Leukemia
	18.Skin Cancer

Some cancers specifically affect gender-related organs, which are not present or affected in the opposite sex which are shown in Table 2.

Table 2: Common Types of Cancer in Men & Women

Serial Number	Cancer commonly found in Men	Cancer Commonly found in Women
1.	Prostate Cancer	Breast Cancer
2.	Penile Cancer	Ovarian & Uterine Cancer
3.	Testicular Cancer	Cervical Cancer

Liposome[36, 37]: A liposome is a small, spherical vesicle made up of one or more phospholipid bilayers surrounding an aqueous (water-filled) core. It is a microscopic structure that can encapsulate both hydrophilic (water-soluble) and lipophilic (fat-soluble) drugs, making it a highly useful drug delivery system in pharmaceutical and biomedical applications. Liposomes were First Discovered by Dr. Alec D. Bangham and his Colleagues while Studying Phospholipids under Electron Microscope, in the Year 1961(Published in 1964); at Babraham Institute, Cambridge. He called them Banghasomes but later on with the suggestion of his colleague it was called Liposomes. He defined liposomes as tiny, Spherical vesicle made of phospholipid bilayer that encloses an aqueous core. Its Aqueous core incorporates Water Soluble(Hydrophilic) Crystalline Drug and, in some cases, it also Includes Genetic material(DNA & mRNA). There are three types of Liposomes according to their Size and number of Lipid bilayer.

It is Structured of:

1.Lipid bilayer (Hydrophobic Bilayer): Works as Protective layer against external factors

2.Aqueous Core (Hydrophilic Core): Carries the drug inside

It is shown in Fig.2, Basic Diagram for Structure of Liposome.

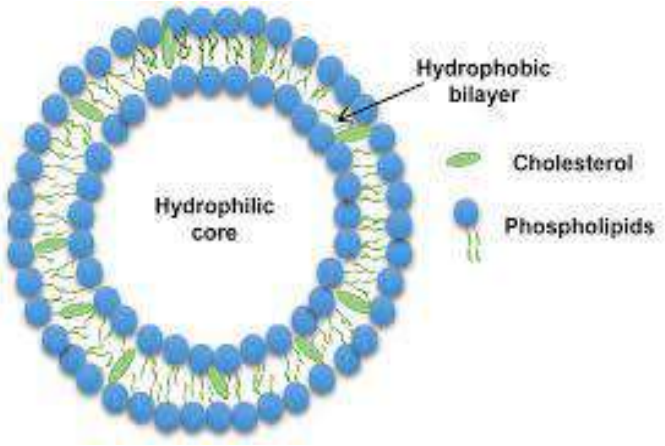

Fig.2: Basic Anatomy (Structure) of Liposome

There are three types of Liposomes:

1.Small Unilamellar Vesicles (SUVs): Single bilayer, small size (20–100 nm).

2. Large Unilamellar Vesicles (LUVs): Single bilayer, larger size (100–1000 nm).

3.Multilamellar Vesicles (MLVs): Multiple concentric bilayers (like an onion).

Targeted Drug Therapy[1, 21, 22, 23]: Targeted drug therapy is a modern approach to treating diseases by delivering drugs specifically to the diseased cells while minimizing damage to healthy tissues. Unlike traditional chemotherapy, which affects both normal and cancerous cells, targeted therapy acts on specific molecular targets that are involved in the growth, progression, and spread of disease.

Advantages: High selectivity for Diseased cells

Lower toxicity and improved patient tolerance

Potential for personalized treatment based on genetic profiling

Nanoparticles[1,10,11]: Nanoparticles are extremely small particles with sizes ranging from 1 to 100 nanometers (nm). At this tiny scale, they exhibit unique physical, chemical, and biological properties that differ significantly from bulk materials. In pharmacy and medicine, nanoparticles are widely used for drug delivery, diagnostics, and therapeutic applications due to their ability to improve drug solubility, stability, and targeting.

Nanoparticle Targeted Drug Therapy (Nanomedicine)[1, 10, 11]:

Nanoparticle Targeted Drug Therapy is an advanced drug delivery approach that uses nanoparticles (1–100 nm in size) to transport therapeutic agents directly to diseased cells or tissues, such as tumors, while minimizing harm to healthy cells. This technology combines the precision of targeted therapy with the efficiency and versatility of nanotechnology, making it highly effective in cancer treatment and other chronic diseases.

Therea are a few types of Nanoparticles Drug Therapy:

- Liposomal Nanoparticles
- Protein Based Nanoparticles

- Inorganic Nanoparticles
- Polymeric Nanoparticles
- Carbon Based Nanoparticles

Advantages of nanomedicine:

- Specifically Targeted Drug Delivery
- Reduces side-effect on non-diseased Cells
- Early and Precise Diagnosis & Action

Disadvantages of nanomedicine:

- A lot about Nanomedicine is yet to be Discovered
- High-cost may not allow everyone to access it
- Can Cause Toxicity
- Can Damage the DNA in Very Rare Cases

Introduction to Liposomal Nanomedicine[1,4,5,6]: Liposomal nanoparticles are nanocarriers which are used for targeted drug therapy. These types of drugs were introduced to emit risk on non-diseased cell. Liposomal nanomedicine offers several advantages, such as reduced toxicity, controlled drug release, and enhanced accumulation at diseased sites through mechanisms like the enhanced permeability.

Liposomes and Cancer[1,2]: Liposomes are having property or natural ability to target cancer. The endothelial walls of all healthy human blood vessels are encapsulated by endothelial cells bounded together by tight junctions. These tight junctions help to stop the large particle in blood from leaking out of the vessel. Such type of arrangement is not there in case of tumor vessel and hence is diagnostically "leaky". This ability is known as enhanced permeability and retention effect. Liposomes of size less than 400 nm, can rapidly enter tumor sites from blood, but these are then kept in bloodstream by endothelial wall in healthy tissue.

Structure of Liposomal Nanomedicine: Liposome contains aqueous solution region that is encapsulated inside a hydrophobic membrane, hence dissolved water-soluble solute cannot easily pass through the lipids. Hence hydrophobic drugs can be dissolved into the membrane, so in this way liposome can carry both hydrophobic as well as hydrophilic molecules. For the drug delivery at the site of action, this lipid bilayer fuses with other bilayer of cell membrane and deliver the contents from liposome. To deliver the drug past the lipid bilayer one can make liposomes in a solution of DNA that are unable to diffuse through the membrane. Liposome does not have lipophobic contents such as water, although it usually does. Hence liposomes are used as models for artificial cells.

Preparation of Liposomal Nanomedicine[1]: Parameters for the liposome preparation method:

1. The physicochemical properties of the material to be entrapped and those of the liposomal ingredients.

2. Nature of the medium in which lipid vesicles are to be dispersed.

3. The active concentration of the entrapped substance and its potential toxicity.

4. Processes involved during delivery of the vesicles.

5. Optimum size, polydispersity and shelf life of vesicles for intended application.

6. Batch-to-batch reproducibility and possibility of large-scale production of safe and efficient liposomal products

Administration of Liposomal Nanomedicine[1,4,5]:

Liposomal Nanomedicine are ingested through Several routes, depending upon the type of drug, target site & Therapeutic goal. The most common route of administration of liposomal nanomedicine is Intravenous Route (I.V. Route). It allows the drug directly to get into the systemic circulation, ensures rapid and controlled delivery to target tissues (like tumors or infections).

Circulation of Liposomal Nanomedicine (Mechanism of Liposomal Nanomedicine):

After intravenous (IV) administration, liposomal nanoparticles enter directly into the systemic circulation and follow a specific path and behavior inside the body:

Circulation in the bloodstream:

Once injected, liposomes circulate freely in the blood plasma. Their circulation time depends on their size, surface charge, and lipid composition.

Protein adsorption (opsonization):

Blood plasma proteins (like complement proteins, immunoglobulins, and apolipoproteins) rapidly bind to the liposome surface. This process is called opsonization.

Recognition and Clearance:

Opsonized liposomes are recognized by the reticuloendothelial system (RES) or mononuclear phagocyte system (MPS), especially in the liver (Kupffer cells) and spleen, leading to their uptake and degradation.

Targeted Delivery (For Modified Liposomes):

Liposomes coated with PEG (polyethylene glycol) or ligands (like antibodies) can evade immune clearance and circulate longer. These "stealth liposomes" passively accumulate in tissues with leaky vasculature, such as tumors or inflamed tissues — a phenomenon known as the Enhanced Permeability and Retention (EPR) effect.

Drug Release:

Once liposomes reach the target site, the drug is released through diffusion, fusion with cell membranes, or liposome degradation, allowing controlled and localized drug delivery.

Liposomal Nanomedicine used in Cancer Treatment: Here is a list of Drug which are Available in Market, clinically approved for treatment of various type of cancer in Table 3.

Table 3: List of Clinically Approved Drugs

Sr. No.	Drug Name	Trade Name	Dosage Form	Route of administration	Company	Indication
1.	Tretinoin	Atragen™	Injectable Fluid	Parenteral	Aronex Pharmaceuticals Inc.	Acute promyelocytic leukemia
2.	Doxorubicin	Doxil®	Injectable Fluid	Parenteral	Sequus Pharmaceutical Inc.	Kaposi Sarcoma
3.	Doxorubicin	Evacet™	Injectable Fluid	Parenteral	The Liposome Company, U.S.A.	Metastatic Breast Cancer
4.	Daunorubicin Citrate	DaunoXome™	Injectable Fluid	Parenteral	NeXstar Pharmaceutical Inc., U.S.A.	Kaposi Sarcoma
5.	Daunorubicin Citrate	Daunoxome	Injectable Fluid	Parenteral	Galen Ltd.	Kaposi Sarcoma

Advances in Liposomal Nanomedicine[1,5,6,7]: Liposomal nanomedicine has rapidly evolved as a versatile drug delivery platform, offering improved therapeutic efficacy and reduced toxicity. Recent advances focus on targeted delivery using ligands such as antibodies, peptides, or tumor-penetrating molecules, alongside stimuli-responsive liposomes that release drugs in response to pH, temperature, or enzymes. PEGylation and alternative surface coatings have enhanced circulation time, while strategies to overcome anti-PEG immunogenicity are emerging. Liposomes are increasingly used for nucleic acid therapeutics, including siRNA and mRNA, benefitting from optimized encapsulation and endosomal escape techniques. Progress in scalable manufacturing, precise characterization, and controlled drug release has facilitated clinical translation, exemplified by FDA-approved liposomal formulations like Onivyde. Despite challenges such as opsonization, heterogeneous tumor uptake, and payload leakage, these innovations highlight liposomes as a mature yet highly tunable platform, bridging the gap between experimental nanomedicine and practical clinical application.

RESULT AND DISCUSSION: The findings indicate that liposomal nanomedicine provides controlled and targeted drug delivery, minimizing damage to healthy cells. The particle size and uniformity suggest efficient tumor accumulation, and surface modifications such as PEGylation or ligand functionalization could further enhance circulation time. Acid-triggered release demonstrates the potential for selective tumor targeting. These results align with previous studies showing that liposomes improve drug bioavailability, reduce systemic toxicity, and enhance therapeutic outcomes. Challenges, including immune clearance and heterogeneous tumor uptake, remain, but careful design and surface engineering can optimize performance, highlighting liposomes as a versatile platform for modern cancer therapy.

CONCLUSION: Liposomal nanomedicine represents a significant advancement in targeted cancer therapy, offering a versatile and efficient platform for delivering both hydrophilic and hydrophobic drugs. By exploiting the enhanced permeability and retention (EPR) effect and incorporating surface modifications such as PEGylation or ligand-based targeting, liposomes improve drug accumulation at tumor sites while minimizing systemic toxicity. Stimuli-responsive designs and applications in nucleic acid delivery further expand their therapeutic potential. Despite challenges such as immune clearance, heterogeneous tumor uptake, and payload stability, ongoing research and technological innovations continue to enhance their safety, efficacy, and clinical applicability, making liposomal nanomedicine a promising strategy in modern cancer treatment.

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