Liposomal Nanoparticle-Based Drug Delivery System for Enhanced Bioavailability in Anticancer Therapy: A Comprehensive Review

[1]Miss.Nikita Mahadev Ghadage, [2]Mr.Harshavardhan M Kole, [3]Miss Ankita A. Barshile
[1]Student, [23]Research Guide
[123]Department of Pharmaceutics
[123]Late Laxmibai Phadtare College of Pharmacy, Kalamb, Pune, Maharashtra, India
[1]ghadagenikita3555@gmail.com, [2]ghadage.3555@gmail.com, [3]nikitamali3555@gmail.com

***Abstract*—Cancer remains one of the leading causes of mortality worldwide and continues to pose a significant challenge in modern healthcare systems. Conventional chemotherapy is associated with several drawbacks such as poor bioavailability, lack of specificity, systemic toxicity, and rapid degradation of anticancer drugs. To overcome these limitations, nanotechnology-based drug delivery systems have gained considerable attention. Among them, liposomes have emerged as one of the most promising carriers due to their biocompatibility, biodegradability, and ability to encapsulate both hydrophilic and hydrophobic drugs. Liposomes are vesicular systems composed of phospholipid bilayers that enhance drug stability and improve pharmacokinetic properties. They facilitate targeted drug delivery through mechanisms such as the enhanced permeability and retention (EPR) effect, thereby increasing drug accumulation in tumor tissues. This review discusses the structure, classification, preparation methods, characterization techniques, advantages, and recent advancements in liposomal drug delivery systems for anticancer therapy. Furthermore, challenges and future perspectives are also highlighted to provide a comprehensive understanding of liposomal nanocarriers in cancer treatment.**

***Index Terms*—Liposomes, Nanoparticles, Drug Delivery System, Anticancer Therapy, Bioavailability, Nanomedicine**

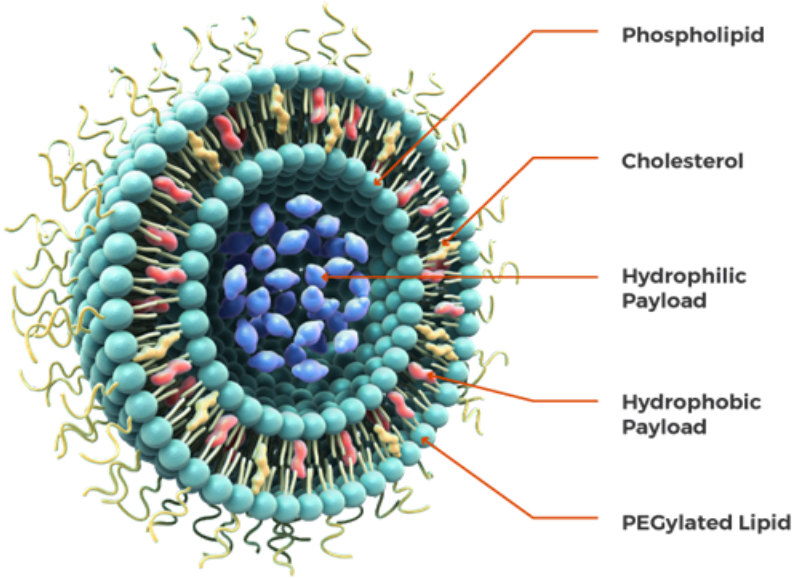
I. Introduction

Cancer is a complex and multifactorial disease characterized by uncontrolled cell proliferation and the ability to invade surrounding tissues and metastasize to distant organs. Despite significant advancements in medical science, cancer continues to be a leading cause of death globally. Conventional treatment modalities such as chemotherapy, radiotherapy, and surgical interventions are widely used; however, they are often associated with severe side effects due to non-specific drug distribution and toxicity to healthy tissues [1].

Many anticancer drugs suffer from poor aqueous solubility, rapid metabolism, and low bioavailability, which significantly limits their therapeutic effectiveness. In addition, the inability to achieve sufficient drug concentration at the tumor site further reduces treatment efficacy. These challenges have led to the development of advanced drug delivery systems that can enhance drug targeting and minimize systemic toxicity [2].

Nanotechnology has revolutionized drug delivery by enabling the design of nanoscale carriers capable of improving drug stability, solubility, and pharmacokinetics. Among various nanocarriers, liposomes have gained considerable attention due to their structural similarity to biological membranes and their ability to encapsulate a wide range of therapeutic agents. Liposomal drug delivery systems have demonstrated significant potential in improving the therapeutic index of anticancer drugs [3].

Figure 1: Structure of Liposome



II. Cancer and Limitations of Conventional Therapy

Conventional chemotherapy is widely used for cancer treatment; however, it is associated with several limitations. One of the major challenges is the non-specific distribution of drugs, which leads to damage to both cancerous and healthy cells. This results in severe side effects such as nausea, hair loss, immunosuppression, and organ toxicity [4].

Additionally, many anticancer drugs exhibit poor solubility and short half-lives, leading to rapid elimination from the body and reduced therapeutic efficacy. Drug resistance developed by tumor cells further complicates treatment. These limitations highlight the need for targeted drug delivery systems that can selectively deliver drugs to tumor tissues while minimizing adverse effects [5].

Nanoparticle-based drug delivery systems, particularly liposomes, have shown promise in overcoming these challenges by enhancing drug stability, improving bioavailability, and enabling targeted delivery [6].

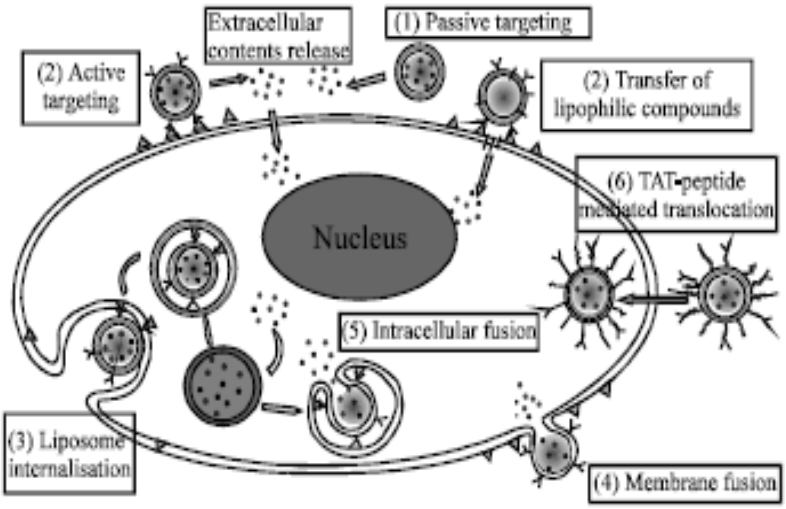
III. Liposomes as Drug Delivery Systems

Liposomes are spherical vesicles composed of one or more phospholipid bilayers enclosing an aqueous core. They are formed when phospholipids are hydrated in an aqueous environment, resulting in the

spontaneous formation of bilayer structures. Liposomes can encapsulate hydrophilic drugs within their aqueous core and hydrophobic drugs within the lipid bilayer membrane [7].

The biocompatibility and biodegradability of liposomes make them suitable for pharmaceutical applications. Liposomes protect drugs from degradation and enhance their circulation time in the bloodstream. Furthermore, liposomes can be modified with ligands or polymers to achieve targeted drug delivery to cancer cells [8].

Figure 2: Mechanism of Liposomal Drug Delivery



IV. Types of Liposomes

Liposomes can be classified based on their composition and functionality. Conventional liposomes are composed of phospholipids and cholesterol and are used for basic drug delivery applications. PEGylated liposomes are surface-modified with polyethylene glycol to increase circulation time and reduce immune recognition. Targeted liposomes are functionalized with ligands such as antibodies or peptides for active targeting of cancer cells. Stimuli-responsive liposomes release drugs in response to environmental triggers such as pH, temperature, or enzymes [9].

Table 1: Types of Liposomes

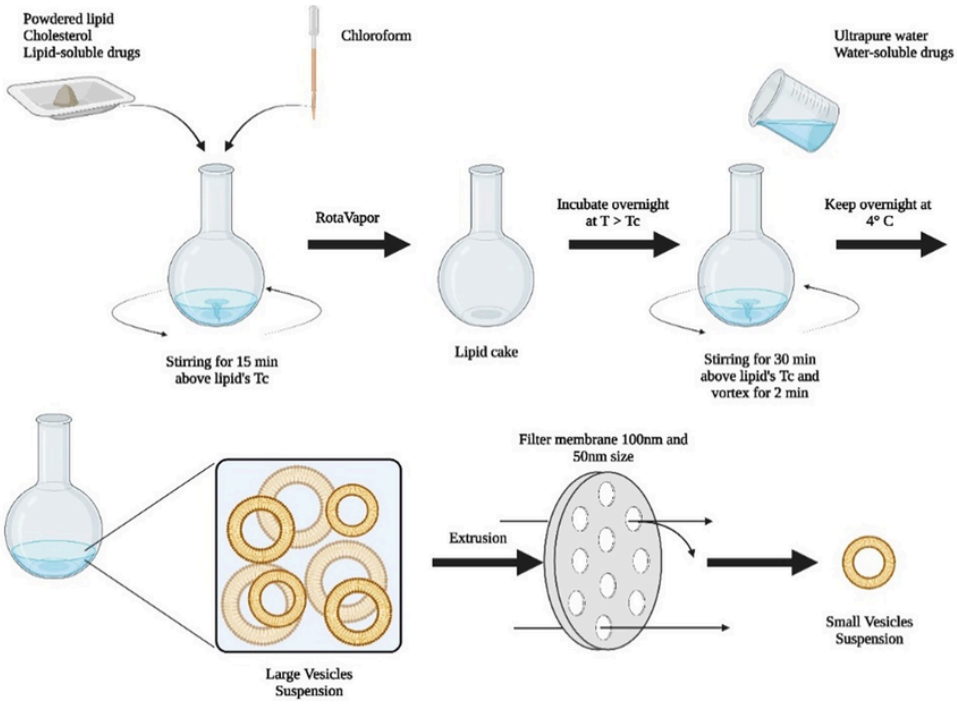
Type of Liposome	Description	Application
Conventional Liposomes	Composed of phospholipids and cholesterol	Basic drug delivery
PEGylated Liposomes	Surface modified with polyethylene glycol	Increased circulation time

Targeted Liposomes	Modified with antibodies or ligands	Targeted cancer therapy
Stimuli Responsive Liposomes	Drug release triggered by pH or temperature	Tumor specific drug release
Immunoliposomes	Liposomes attached with antibodies	Selective cancer cell targeting

V. Methods of Liposome Preparation

Several techniques have been developed for liposome preparation, including thin film hydration, ethanol injection, reverse phase evaporation, and detergent removal methods. The thin film hydration method is the most widely used technique, in which lipids are dissolved in organic solvents and evaporated to form a thin film. The film is then hydrated with an aqueous drug solution to produce liposomes [10].

Figure 3: Thin Film Hydration Method



VI. Characterization of Liposomes

Characterization of liposomes is essential to evaluate their physicochemical properties and performance. Important parameters include particle size, zeta potential, entrapment efficiency, drug content, and in vitro drug release. Particle size influences biodistribution and cellular uptake, while zeta potential

indicates stability. Entrapment efficiency determines the amount of drug encapsulated within liposomes [11].

Table 2: Characterization Techniques

Parameter	Technique Used	Purpose
Particle Size	Dynamic Light Scattering	Determines vesicle size
Zeta Potential	Zeta Analyzer	Determines surface charge and stability
Morphology	TEM / SEM	Determines vesicle shape
Drug Entrapment Efficiency	UV Spectroscopy / HPLC	Determines drug loading
In vitro Drug Release	Dialysis method	Evaluates release kinetics
Stability Studies	Storage studies	Determines shelf life

VII. Literature Review

Several studies have demonstrated the effectiveness of liposomal drug delivery systems in anticancer therapy. Recent research has focused on improving drug targeting, enhancing bioavailability, and reducing toxicity through advanced liposomal formulations. Liposomal formulations of drugs such as doxorubicin and vincristine have shown improved therapeutic outcomes and reduced side effects compared to conventional formulations [12].

Table 3: Recent Studies on Liposomal Drug Delivery for Anticancer Therapy

Sr. No	Author (Year)	Drug / Compound	Liposome Method	Key Findings
1	Teixeira et al., 2025	Pyrimidine based anticancer compound	Phosphatidylcholine liposomes	Particle size <150 nm with high encapsulation efficiency and sustained drug release
2	Allateef et al., 2024	Coumarin + Phenylbutyric acid	Liposomal co-encapsulation	Improved cytotoxicity against breast, lung and colorectal cancer cells
3	Hamad et al., 2024	Liposomal nanocarriers	Bibliometric study	Liposomes widely used in targeted drug delivery and cancer nanomedicine
4	Liu et al., 2024	Vincristine sulfate	pH gradient loading	Improved pharmacokinetics and

				enhanced anticancer activity
5	Vishnu et al., 2024	Vinca alkaloids	Ultrasonication method	Liposomes improved drug stability and targeting ability
6	Kumar et al., 2021	Decitabine	Thin film hydration	High encapsulation efficiency and sustained drug release
7	Ahmed et al., 2020	Doxorubicin + Celecoxib	Co-loaded liposomes	Synergistic anticancer activity and reduced toxicity
8	Xu et al., 2020	Rubropunctatin	Liposomal carrier system	Improved solubility, stability and apoptosis induction

VIII. Advantages of Liposomal Drug Delivery

Liposomal drug delivery systems offer several advantages, including improved bioavailability, reduced toxicity, controlled drug release, and enhanced drug stability. The ability of liposomes to accumulate in tumor tissues through the enhanced permeability and retention effect significantly improves therapeutic efficacy [13].

Figure 4: Advantages of Liposomes

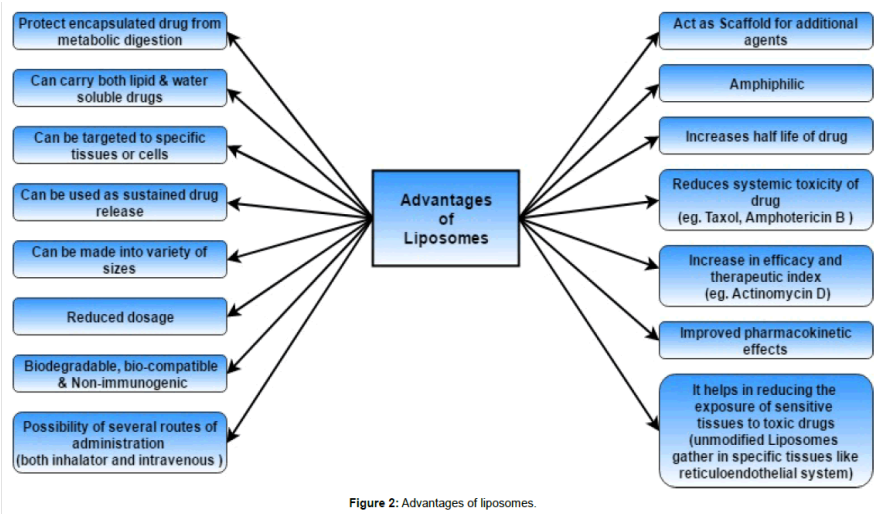


Figure 2: Advantages of liposomes.

IX. Challenges and Limitations

Despite their advantages, liposomal drug delivery systems face challenges such as stability issues, drug leakage, high production costs, and scalability problems. Addressing these challenges is essential for the successful commercialization of liposomal formulations [14].

X. Future Perspectives

Future research is focused on developing multifunctional liposomes capable of targeted delivery, controlled release, and improved therapeutic outcomes. Advances in nanotechnology and molecular biology are expected to enhance the clinical potential of liposomal drug delivery systems [15].

XI. Conclusion

Liposomal nanoparticle drug delivery systems represent a promising strategy for improving the efficacy and safety of anticancer therapy. Their ability to enhance bioavailability, reduce toxicity, and provide targeted delivery makes them valuable tools in modern pharmaceutical research. Continued advancements in this field are expected to revolutionize cancer treatment in the future.

References

[1] Raina S, Sharma V. World J Pharm Sci. 2019.
[2] Noble CO et al. Cancer Chemother Pharmacol. 2009.
[3] Teixeira S et al. Pharmaceuticals. 2025.
[4] Allateef A et al. J Appl Pharm Sci. 2024.
[5] Hamad I et al. Pharmaceutics. 2024.
[6] Liu Z et al. Int J Pharm. 2024.
[7] Sharma D et al. PharmaTutor. 2018.
[8] Ahmed KS et al. J Liposome Res. 2020.
[9] Xu X et al. Nanomedicine. 2020.
[10] Verma S et al. Int J Drug Dev Res. 2017