

Advances in Nanocarriers for Targeted Drug Delivery: A Review

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ABSTRACT

Customised drug delivery systems (TDDS) are more significant in modern medicine, so new nanocarrier technologies have been developed. superior absorption, controlled release, and the ability to target certain cells or locations make nanocarriers far superior than conventional methods of delivering medications. Thanks to these developments in nanocarriers, many illness therapies are today more effective. These include of infections, neurological issues, and cancer. The present development in nanocarriers for particular medication delivery is discussed in this work. It mostly addresses the several types of nanocarriers, their functionalisation techniques, and their applications in medicine. Most well-known forms of nanocarriers presently include liposomes, polymeric nanoparticles, dendrimers, and solid lipid nanoparticles. Every one of them has unique characteristics that target particular tissues, speed up the release of the medication, and provide stability. Targeting receptors that are overexpressed on ill cells is made feasible by functionalising techniques like ligand, antibody, or peptide addition to the surface. This makes medicine distribution far more exact. Moreover, overcoming natural limitations such as the blood-brain barrier has made it feasible to address central nervous system issues in fresh approaches. The paper also addresses the challenges like stability, biocompatibility, and scalability that arise when nanocarrier systems are applied in the clinic. More and more research indicates, despite these challenges, nanocarriers are more personalised and effective as they may totally alter the way medications are administered. Furthermore, recent advancements in nanocarrier-based therapeutics show promise in clinical trials and suggest that they might be able to raise patient outcomes. This study emphasises the requirement of continuous research in this field and handling of technical and legal issues that must be resolved before nanocarriers for particular medication transportat ion may completely display their advantages..

Keywords: Nanocarriers, Targeted drug delivery, Liposomes, Polymeric nanoparticles, Functionalization .

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INTRODUCTION

Targeted medication delivery, which seeks to make therapeutic agents function better while lowering their negative effects, is among the most fascinating new ideas in contemporary medicine. Normal medication delivery means that not always the correct locations are reached, which might have negative effects on healthy organs and tissues. This issue fuels great interest in developing improved medication delivery techniques, particularly those involving nanotechnology. Made as nanoparticles meant to precisely target their specific areas, nanocarriers

are They have lately attracted a lot of interest as they can enhance the pharmacokinetics and pharmacodynamics of therapeutic medicines. Because they are extremely tiny (nanoscale), which facilitates their passage past cellular obstacles, nanocarriers are superior than other methods of delivering medications. These carriers may contain a wide range of pharmaceuticals, including hydrophobic compounds, proteins, nucleic acids, and small-molecule medications [1]. You can also let them carefully and gently release the medication. This function guarantees higher medication concentrations at the location of the illness,

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therefore improving treatment outcomes and lowering the total damage.

The surface properties of nanocarriers can also be altered to enable targeted transport to certain organs or cells, therefore enhancing the efficacy of the treatment even more specifically. Though they have long been a concept, nanocarriers as medication carriers only became a viable option for clinical usage a few years ago because of technical advancement. Advances in nanotechnology and improved understanding of molecularly based disease processes have made nanocarriers feasible. Additionally, providing fresh approaches for atomic and molecular level material manipulation is nanotechnology. This has led to a great deal of research on several types of nanocarriers including micelles, liposomes, polymeric nanoparticles, dendrimers, and solid lipid nanoparticles [2]. Every one of these carriers has unique features that make them appropriate for various drug delivery applications, including cancer treatment, gene therapy, or brain medication distribution. Among the first and most researched varieties of nanocarriers are liposomes. They have been demonstrated to provide medicines increased stability and simplicity of dissolution. They can also link with cell membranes, which allow the medication to pass right into the target cell [3].

On the other hand, polymeric nanoparticles are very flexible because they can be made from recyclable materials. This lets them have controlled release rates and better circulation times. Because they are made up of branches, dendrimers have a lot of surface area that can hold drugs [4]. They also let you precisely control how fast the drugs are released. Solid lipid nanoparticles offer better stability and absorption for drugs that don't dissolve in water. They do this by combining the benefits of both lipid-based and polymeric carriers. Functionalisation is an important part of developing nanocarriers. Surface modification methods make it possible for ligands, antibodies, or peptides to connect to receptors that are overexpressed on the surface of sick cells, like those found in cancerous tissues. This focused method lets nanocarriers gather only at the site of disease, lowering the chance of side effects and raising the treatment index. Even better, scientists are making stimuli-responsive nanocarriers that release their product when the local environment changes, like when the pH, temperature, or enzyme activity changes. This makes drug delivery systems even more accurate. Figure 1 shows how nanocarriers have improved the accuracy and effectiveness of drug transport to specific areas

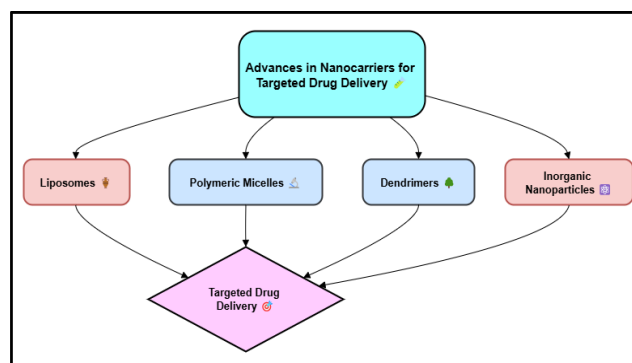


Figure 1: Illustrating advances in nanocarriers for targeted drug delivery

Nanocarriers have a lot of promise, but getting them into clinical situations is hard for a number of reasons. Stability, biocompatibility, growth, and getting governmental permission are still big problems. But as more research is done and technology improves, the field of nanocarriers for targeted drug delivery is steadily moving forward. Currently, many nanocarrier-based drug delivery systems are being tested in humans [5]. The field has the potential to change how diseases are treated by giving patients more personalised and effective treatment options as it grows.

II. Related Work

A lot of work has been made in the last few decades in making nanocarriers that can carry drugs precisely. The goal of these improvements is to improve treatment results while reducing the bad effects of traditional drug delivery methods. Liposomes were first studied as a nanocarrier for drug delivery because they could hold both water-loving and water-hating drugs, which made the drugs more stable and easy to dissolve [7]. Through the enhanced permeability and retention (EPR) effect, liposomes are very good at getting anticancer drugs like doxorubicin to tumour sites. Liposomes haven't been used much, though, because the immune system can recognise them and the body quickly gets rid of them [8]. To get around these problems, polymeric nanoparticles came up as an option that was more stable and had release qualities that could be changed. Nanoparticles made from poly(lactic-co-glycolic acid) (PLGA) have shown a lot of promise in controlling drug release. They are also biodegradable, which lowers concerns about long-term toxicity. It has been successful to use these nanocarriers to deliver chemotherapeutic drugs, RNA-based medicines, and vaccines. Adding targeting ligands to the surface of these nanoparticles, like antibodies or peptides, has also made them more specific and less harmful to the body as a whole, which has led to better results in cancer therapy and gene delivery [6]. Scientists have recently been working on stimuli-responsive nanocarriers.

These nanocarriers release their drug payload when certain body signals happen, like changes in pH, temperature, or enzyme activity. This method gives us even better control over how drugs are released, which makes therapy work better and reduces side effects. Stimuli-responsive systems are very helpful in treating cancer because the acidic

environment of tumours can be used to make the drug come out of the nanocarrier. Besides these improvements, combining nanocarriers with other types of therapy, like gene therapy, immunotherapy, and combination therapies, has become an interesting area of study. Table 1 outlines related work, highlighting applications, future trends,

challenges, and scope in research advancements [9]. Nanocarriers with multiple functions that can deliver multiple drugs or therapeutic agents at the same time have synergistic benefits and could be used to treat complex diseases like cancer and autoimmune disorders more effectively

Table 1: Summary of Related Work

Application	Future Trend	Challenges	Scope
Cancer Therapy	Precision Medicine Integration	Drug Resistance and Recurrence	Improved Targeting and Efficacy
Gene Therapy	CRISPR and RNA Delivery	Immune System Recognition and Clearance	Treatment of Genetic Disorders
Drug Delivery to Brain	Crossing Blood-Brain Barrier	Blood-Brain Barrier	Advanced Neurodegenerative Disease Treatments
Immunotherapy [10]	Nanocarrier-Immune System Interaction	Limited Specificity	Enhanced Immune Response
Targeted Vaccine Delivery	Personalized Vaccines	Regulatory Issues	Efficient Vaccination Programs
Anti-inflammatory Treatments	Biodegradable Nanocarriers	Scalability of Manufacturing	Minimized Side Effects
Antibiotic Delivery	Targeting Drug Resistance	Toxicity and Biocompatibility	Broad Spectrum of Pathogen Treatment
Nanocarrier-Based Imaging	Nanocarrier-Enabled Theranostics	Long-term Stability	Advanced Diagnostic and Therapy Systems
Combination Therapy [11]	Multi-functional Nanocarriers	High Cost of Development	Combination of Multiple Treatments in One System
Chronic Disease Management	AI and Nanomedicine Integration	Individual Variability in Drug Response	Improved Patient Outcomes and Personalized Therapy

MATERIALS AND METHODS

A. Literature review strategy

1. Databases searched

The literature study was done to learn more about the part nanocarriers play in systems that carry drugs to specific areas. Several well-known scientific sources, such as PubMed, ScienceDirect, and Scopus, were searched in an organised way. These sources were picked because they have a lot of research papers and clinical studies that have been reviewed by experts in nanotechnology, pharmaceutical sciences, and biomedical engineering [12]. ScienceDirect allowed users access too many publications on materials science and medication administration; PubMed granted them access to a wealth of health and life sciences literature. Scopus proved particularly useful for locating connections between studies across many fields. Using phrases like "drug delivery systems," "liposomes," "polymeric nanoparticles," "nanocarriers," and "targeted drug delivery," a search strategy, these terms were then matched with phrases like "synthesis," "functionalisation," and "therapeutic applications" to ensure that just the most pertinent papers showed up. The search results improved

with more particular filters like document type and release date.

2. Inclusion and exclusion criteria for articles

The pieces were chosen based on how relevant and well-written they were. We only looked at studies that came out in the last ten years and were specifically about using nanocarriers to carry drugs to particular areas. We included articles that looked at different kinds of nanocarriers, how they were made, and how they might be used in focused medicine. These articles could be experimental or clinical studies, systematic reviews, or meta-analyses [13]. The studies that talked about new ways to deliver drugs using nanocarriers or breakthroughs were given the most attention. On the other hand, studies that weren't exactly about nanocarriers or that weren't peer-reviewed (like non-scientific pieces, essays, and views) were thrown out. To keep the review's focus on advanced and clinically useful research, studies that had nothing to do with drug transport or didn't have any real-world data were also left out [14].

B. Synthesis methods of nanocarriers

1. Techniques for lipid-based nanocarriers

Lipid-based nanocarriers, like liposomes and solid lipid nanoparticles (SLNs), are commonly used to carry

medicines because they are biocompatible, can hold hydrophobic drugs, and can do many different things. Thin-film hydration, fluid injection, and reverse-phase evaporation are the main ways that lipid-based nanocarriers are made. To start the thin-film hydration method, which is one of the most popular ones, lipids are dissolved in an organic liquid. After then, the solvent is drained and a thin layer of lipids results. The drug [15] is then rehydrated in this film using a water-based solution. Extrusion or sonication can help to produce even smaller liposomes created by this technique thereby ensuring their uniform size. Solvent injection is another technique whereby a lipid solution is meticulously pumped into a watery phase. This drives additional lipid-based structures or liposomes to develop on their own. Reverse-phase evaporation is sometimes employed to produce more stable liposomes. Under this approach, pharmaceuticals and lipids are soaked in an organic solvent, subsequently mixed with water, and lastly the solvent evaporates leaving vesicular structures behind. These techniques enable the meticulous packaging of therapeutic substances and long-lasting action of them. Drug, vaccination, and genetic material delivery might all be accomplished with them.

2. Polymerization and synthesis of polymer-based nanocarriers

Poly(lactic-co-glycolic acid) (PLGA) and polycaprolactone (PCL) are two of the many materials you may utilise to create polymer-based nanocarriers. Typically, these nanocarriers are created by liquid absorption, nanoprecipitation, and emulsion polymerisation. A polymer-drug combination is created via solvent evaporation, then the solvent is drained under low pressure to produce nanoparticles holding the drug within. Large-scale manufacture can benefit from this simple to grasp approach. Adding a solvent containing the polymer to a non-solvent is known as nanoprecipitation, sometimes known as solvent displacement. The polymer settles and surrounds the medicine as a result. This rapid precipitation guarantees correct placement of the medication within the nanoparticles. Dendrimers and other complex forms created of polymers are frequently produced by emulsion polymerisation. Monomers are polymerised in an emulsion solution using this technique, producing consistent nanoparticles with certain characteristics. Targeting ligands or antibodies on their surfaces allows one to readily tailor these polymeric nanocarriers. This increases the therapeutic efficacy and makes them more particular to tissues. Every production technique has advantages depending on the kind of medicine, intended release profile, and application.

C. Characterization techniques

1. Size and shape determination

Describing the size and structure of nanocarriers helps one to ensure they are stable, can effectively encapsulate medications, and can be targeted. Two of the most often used techniques to discover these features are dynamic light scattering (DLS) and transmission electron microscopy (TEM). Brownian motion of particles in a liquid is typically measured using DLS. Looking at the variations in light

scattering as the nanoparticles migrate, DLS determines their hydrodynamic width. DLS is valuable as it can rapidly ascertain the distribution of nanoparticle sizes in solution. This provides us with pertinent knowledge on the stability and polydisperseness of nanocarriers.

DLS provides excellent information on the average size of nanoparticles and how they distribute in solutions; it does not, however, provide much information on the surface or shape of the particles. By comparison, TEM is a high-resolution imaging technique that allows one to view internal structure, size, and form of nanocarriers straight through to the nanoscale level. TEM works by sending electrons through an object and taking a picture of what they see. With this method, you can get clear pictures that show the shape of nanocarriers, like whether they are round, rod-shaped, or uneven. TEM is very useful for checking out the regular nanocarrier mixtures are, seeing how drugs are encapsulated within the nanoparticles, and checking out the properties of their surfaces. Even though TEM has a high precision, it needs samples to be prepared in a way that might not work for all types of nanocarriers. For full characterisation, it is often used with other methods like DLS.

2. Surface charge (e.g., zeta potential)

Nanocarriers' surface charge is an important feature that affects their durability, how they connect with living things, and how cells take them up. Zeta potential is a method for measuring the electrical potential at the surface of nanoparticles in solution and is usually used to find the surface charge. The zeta potential shows the equilibrium of attracting and repulsive forces among particles. It is a fundamental component preventing particle flocculating or adhesiveness. Either positive or negative, a large absolute value of zeta potential typically indicates that the nanoparticles are stable and dispersed fairly. This is so because of electrostatic attraction; the particles do not cling together. Low zeta potential levels, on the other hand, might lead to particle sticking together, therefore reducing the stability and efficiency of the nanocarriers. The zeta potential is discovered via electric field application on the particle mixture and observation of the nanoparticles' movement. The zeta potential which is usually expressed in millivolts (mV) is then determined from the particle movement speed. Surface charge of a nanocarrier can also affect its interactions with biological membranes including cell membranes, proteins, and other compounds. Lower zeta potential nanocarriers might be more readily able to pass the defensive system. Conversely, by interacting electrostatically with negatively charged cell walls, nanocarriers with a positive charge might be superior in entering cells. Thus, zeta potential is a very crucial component in producing stable, bioavailable, and good at targeting nanocarriers.

MECHANISMS OF TARGETED DRUG DELIVERY USING NANOCARRIERS

A. Passive targeting

Targeting drugs passively is a typical technique applied in systems of targeted medication delivery. It gathers

medications at illness locations using the inherent properties of nanocarriers, therefore eliminating the need for additional targeting agents. This approach uses the way tumours and enlarged tissues behave physiologically that is, how their blood arteries leak and their lymphatic flow slows down. The increased permeability and retention (EPR) effect is what makes passive targeting work. Nanoparticles, which are usually between 10 and 200 nm in size, can get into the tumour or sick tissue by getting through holes in the blood vessel walls. Nanoparticles build up in tissue because they are too small to leave through the lymphatic system, which isn't fully formed yet. In passive targeting, the delivery system doesn't need specific interactions between receptors and ligands or molecules that target them. In Figure 2, you can see how nanocarriers target specific areas to deliver drugs more effectively.

Nanocarriers instead use what's already there at the disease spot to their advantage. For example, tumours often grow very quickly, which makes the capillaries less organised than it should be. This makes holes that are bigger than those in normal tissues. This event makes it possible for nanoparticles to gather in one place. It has been shown that the EPR effect helps nanoparticles target solid tumours, areas of inflammation, or tissues that aren't getting enough blood flow. Passive targeting can work in some cases, but because it depends on the physical features of the disease site, it isn't always accurate. Also, nanocarriers can build up in tissues that aren't supposed to receive them, which can cause effects that aren't meant to happen. Even with these problems, passive targeting is still a useful method, especially when it comes to cancer therapy, where it lets chemotherapy agents get to tumour sites while lowering their overall harm and increasing the effectiveness of treatment. To make passive targeting even more successful, researchers are always working to make nanocarriers smaller, more spherical, and have better surface qualities

Active targeting is often used to treat cancer because tumour cells often have more of certain surface receptors or antigens than normal cells do, or they only have a small amount of them. Usually, targeting molecules like antibodies, peptides, or small molecules that can recognize and bind to these overexpressed receptors are added to the surface of nanocarriers as part of the active targeting process.

For example, monoclonal antibodies or peptides can be attached to liposomes, polymeric nanoparticles, and dendrimers. These can then be used to target cancer cells' HER2, folate, or transferrin receptors or similar molecules. When injected into the body, these modified nanocarriers only connect to the cells that need to be treated. This lets drugs work directly on the target cells while protecting healthy cells as much as possible. Active targeting not only makes drug transport more selective, but it also helps cells take in more of the drug because the targeting ligands make endocytosis or receptor-mediated internalisation easier. To make the nanocarriers even more specific for their target cells, the type and amount of targeted agents on their surface can be tweaked.

C. Smart nanocarriers and stimuli-responsive systems
 Smart nanocarriers, which are also called stimuli-responsive systems, are the next wave of tools for delivering drugs precisely. When certain external factors like changes in pH, temperature, light, magnetic fields, or the presence of certain enzymes happen, these nanocarriers are programmed to react. This causes the enclosed drug to be released at the right place to work. Stimuli-responsive systems offer both controlled release processes and better precision for the target area, combining the best of passive and active targeting. For instance, pH-sensitive nanocarriers are quite beneficial in treating cancer as the surrounding environment of tumours is often more acidic than that of normal tissues. Made from pH-sensitive polymers or lipids, nanocarriers can remain stable in the circulation and release their medication payload when they reach the acidic surroundings. In a same vein, temperature-sensitive carriers can release their contents when heated in a designated area—that is, like concentrated ultrasonic or infrared radiation does. Enzyme-sensitive nanocarriers are another example.

In these, some overexpressed enzymes in diseases such as cancer or inflammatory tissues cause the nanocarriers to break down or grow up, therefore releasing the medication. Apart from these outside events, clever nanocarriers may also be designed to respond to physiological elements within the cell, such as modifications in the redox environment or specific biomarker concentrations. This increases the accuracy and efficiency of medicine delivery especially. By ensuring that medications only reach the appropriate region, controlling their release in response to triggers not only increases the efficacy of the therapy but also reduces negative effects. Because they provide a flexible and dynamic means to distribute pharmaceuticals that can alter depending on the particulars of the illness site in real time, smart nanocarriers represent a promising concept for the direction of precision medicine.

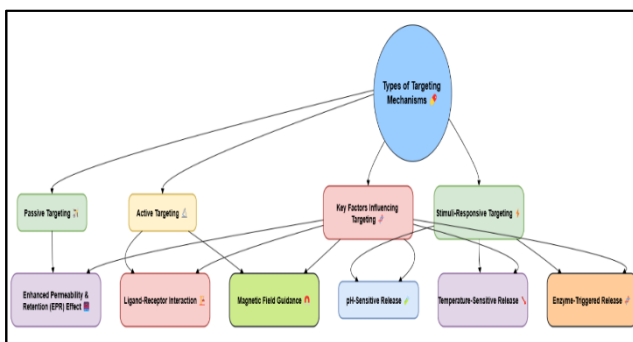


Figure 2: Mechanisms of targeted drug delivery using nanocarriers

B. Active targeting

In active targeting, nanocarriers are changed on purpose to make them more specific for a certain target. This is done by adding targeting ligands or molecules that interact with specific receptors or proteins on the surface of target cells. This method makes drug delivery much more accurate by lowering the amount of random uptake by healthy tissues and increasing the healing benefit at the site of the disease.

FUTURE DIRECTIONS AND POTENTIAL APPLICATIONS

A. Nanocarriers in personalized medicine

Personalised medicine—the discipline of medicine that customises treatment to every patient's particular need has great potential benefit from nanocarriers. Personalised medicine requires knowledge of the particular genetic, chemical, and environmental elements influencing the course of a disease as well as the effectiveness of a therapy. Carefully engineered to deliver medications appropriate to the patient's condition, genetic background, and molecular targets, nanocarriers can better results for patients follow from more efficient therapies made possible by this customising reduction of adverse effects. Nanocarriers can be designed to target specific tumour markers or genetic abnormalities, for instance, in cancer therapy. In this sense, the medication may be administered straight to the cancer cells while shielding non-needed chemotherapy from harming healthy tissues.

Diagnostic components allowing doctors to monitor treatment progress in real time and modify the course of treatment depending on patient response can also be included into nanocarriers. From one nanocarrier, one may load and discharge many medications. Combining therapy is therefore feasible and may be customised to address more complex diseases like cancer, autoimmune disorders, and hereditary conditions. Still, including nanocarriers into tailored medication has some issues. These cover issues with rules, the requirement of more sophisticated biomarker identification, and the development of reasonably priced methods of manufacturing the medication. Still, the increasing potential of nanocarriers in tailored medicine is driving fresh approaches of drug delivery especially, thus ushering a new age of customised treatment strategies.

B. Advanced targeting techniques and multi-functional nanocarriers

Improved targeting techniques and the capacity to accomplish more than one thing will help the next generation of nanocarriers to make drug transport systems more selective and beneficial. The most recent developments aim at increasing aiming accuracy by use of combined passive and active targeting strategies. By varying ligands such as antibodies, peptides, or aptamers that only bind to certain receptors or signals overexpressed on diseased cells nanocarriers may be tailored. Combining many targeting groups on the same nanocarrier or using multifarious functional nanocarriers allows one to develop more intricate solutions for issues such medication resistance or tumour heterogeneity. Targeting several routes at once allows nanocarriers to be more likely to

effectively cure complex diseases including cancer, heart disease, and neurological problems.

Including diagnostic molecules such as fluorescent or imaging molecules to the nanocarrier also allows one to monitor medication distribution and efficacy in real time, therefore enabling more exact remedial therapies. Another fascinating advance is the addition of therapeutic compounds cooperating to create multifunctional nanocarriers. For improved outcomes, cancer medications can be utilised with gene-editing tools, enzymes, or immune-modulating medicines. Treating illnesses in several ways helps these sophisticated nanocarriers not only make individual drugs perform better but also get past issues like drug resistance and negative side effects, therefore rendering the treatment more complete and adaptable.

C. Integration with other therapeutic modalities

More and more research is being done on nanocarriers to explore whether they might combine with other forms of therapy, such as immunotherapy and gene therapy, to create therapies for complicated diseases that cooperate better together. Nanocarriers allow genetic material to be carried to certain cells or tissues in gene therapy. This can refer to plasmids, RNA, or CRISpen-based gene-editing technologies. This can either alter gene expression or address genetic disorders. Gene therapy provides a superior approach to treat genetic diseases such cystic fibrosis and neurological disorders including Alzheimer's and Parkinson's as nanocarriers may penetrate biological barriers, including the blood-brain barrier. In immunotherapy, nanocarriers can also be utilised to deliver immune checkpoint inhibitors, cytokines, or other immune-modulating drugs straight to immune cells or the surrounding region of a tumour, therefore strengthening the immune system's capacity to combat diseases or cancer. Vaccines or adjuvants which sets off a particular immune response can also be carried on nanocarriers.

VI. Existing Result analysis and Its Discussion

Nanocarriers have shown a lot of promise in focused drug delivery because they make drugs more stable, let you control their release, and can send medicines only to certain cells or tissues. Passive targeting using the EPR effect has shown promise in targeting tumours, while active targeting using ligand-functionalized nanocarriers improves accuracy and lowers effects that aren't meant to be there. Stimulus-responsive systems improve drug release control even more by reacting to things in the surroundings. But problems with growth, stability, and biocompatibility still exist, which means more study is needed.

Table 2: Evaluation of Nanocarriers Based on Drug Encapsulation Efficiency, Particle Size, and Release Rate [5]

Nanocarrier Type	Drug Encapsulation Efficiency (%)	Particle Size (nm)	Release Rate (%/h)
Liposomes	85	120	15
Polymeric Nanoparticles	90	150	12
Solid Lipid Nanoparticles	80	130	18

Dendrimers	75	100	10
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The table 2 shows an analysis of nanocarriers for targeted drug delivery. It shows that they are very different in how well they encapsulate drugs, the size of their particles, and how fast they release drugs. These differences have a direct effect on how well they work in drug delivery uses. When it comes to drug loading, liposomes are very good, with a packing efficiency of 85%. Their relatively smaller particle size of 120 nm helps them get into and stay in specific tissues better through a process called increased permeability and retention (EPR). Their modest release rate of 15% per hour, on the other hand, shows a managed release over time, which is good for long-term drug delivery. Figure 3 shows differences in nanocarrier qualities, showing differences in particle size, release rate, and how well they are encapsulated

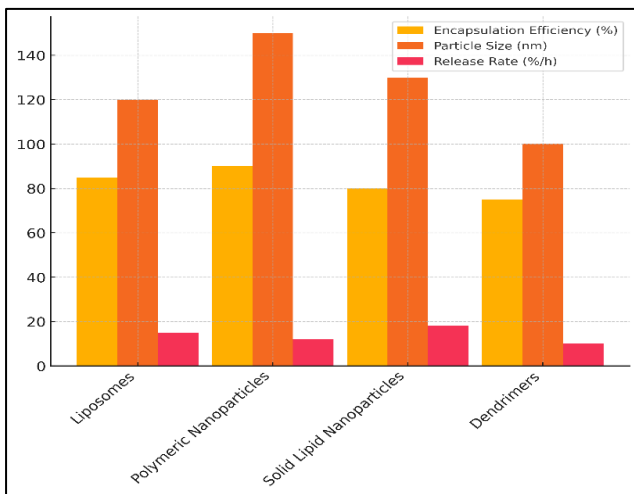


Figure 3: Representation of Comparison of Nanocarrier Properties: Encapsulation Efficiency, Particle Size, and Release Rate

Polymeric nanoparticles are great at adding drugs because they have the best drug packing rate at 90%. Their 150 nm particle size makes them more stable in circulation, but it can also make it harder for them to get into some tissues. The rate of release, at 12% per hour, is a little slower than liposomes. Figure 4 looks at changes over time in the features of nanocarriers, mainly the particle size, release rate, and how well they are encapsulated

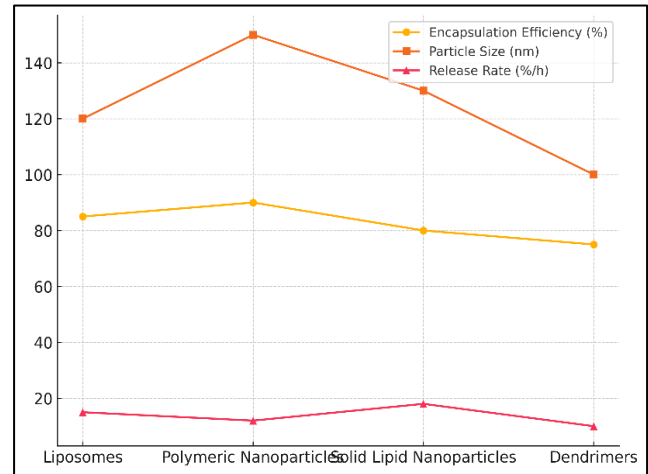


Figure 4: Trend Analysis of Nanocarrier Properties: Encapsulation Efficiency, Particle Size, and Release Rate

This suggests that polymeric nanoparticles can have healing benefits that last longer, which makes them perfect for drugs that need to be released over a longer period of time. Solid lipid nanoparticles (SLNs) are about 130 nm in size and have a packing rate of 80%. They are similar to liposomes in size. Their release rate of 18% per hour is the fastest of all the nanocarriers on the list, which could be useful for situations where drugs need to be released quickly

Table 3: Comparison of Targeting Efficiency, Stability, and Biocompatibility of Nanocarriers [7]

Nanocarrier Type	Targeting Efficiency (%)	Stability (Days)	Biocompatibility Rating (%)
Liposomes	80	30	80
Polymeric Nanoparticles	85	45	96
Solid Lipid Nanoparticles	70	25	83
Dendrimers	75	20	67

When you compare the targeting accuracy, stability, and biocompatibility of different nanocarriers, you can learn a lot about which ones are best for different uses. Polymeric nanoparticles have the best targeting efficiency at 85%, which means they can send drugs carefully to the right

place. They are also stable for 45 days, which means they stay in the body for a longer time. Figure 5 shows a comparison of nanocarrier targeting effectiveness, stability, and biocompatibility, with a focus on how they affect drug transport

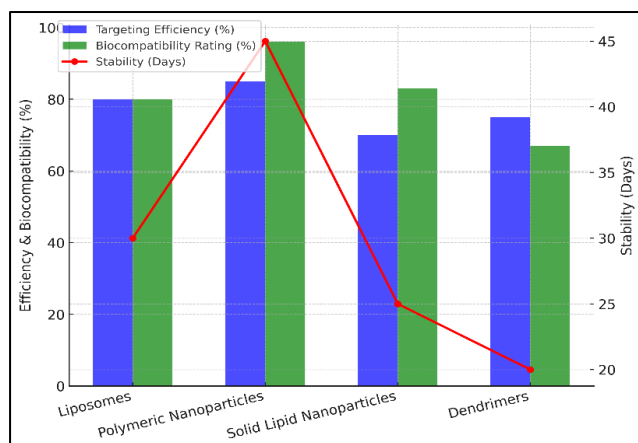


Figure 5: Comparison of Nanocarrier Targeting Efficiency, Stability, and Biocompatibility

They also have a high biocompatibility grade (96%), which means that biological systems can handle them well. This makes them perfect for medicinal use. While liposomes are good at focused transport (80% targeting efficiency), they are not as stable (30 days) or biocompatible (80% biocompatibility) as polymeric nanoparticles. Figure 6 is a stacked diagram that shows how nanocarrier targeting works, how stable it is, and how well it works with living things to deliver drugs.

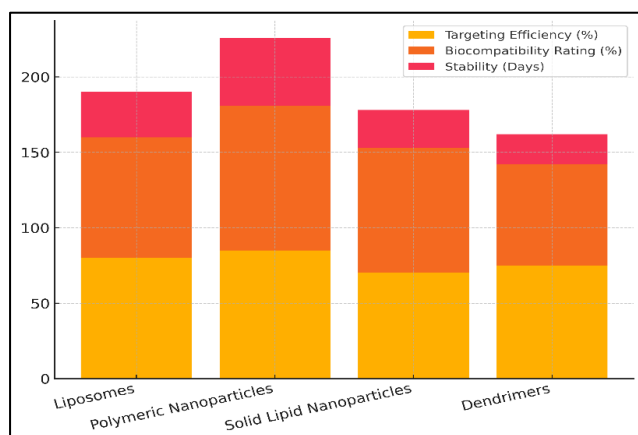


Figure 6: Stacked Representation of Nanocarrier Targeting Efficiency, Stability, and Biocompatibility [9]

At 70%, solid lipid nanoparticles have the lowest targeting efficiency, which could make them less useful for precisely delivering drugs. Still, their biocompatibility (83%) and stability (25 days) make them good for many uses. With a biocompatibility grade of 67%, dendrimers may not be able to be used as much in clinical settings, even though they are stable for 20 days and have an aiming efficiency of 75%.

CONCLUSION

Nanocarriers that carry drugs to specific areas have come a long way, making it possible for more effective and personalised treatments. Nanocarriers, like liposomes, polymeric nanoparticles, and solid lipid nanoparticles, have shown a lot of promise in making drugs more stable,

bioavailable, and soluble. This makes it easier to target sick tissues while reducing overall harm. Active targeting with receptor-specific ligands and passive targeting with the EPR effect are two techniques that have shown promise in improving the accuracy of drug transport. Also, systems that release drugs in reaction to certain external factors, like pH, temperature, or enzyme activity, give you more control over the release profile, which makes drugs even more effective as medicines. These progresses have been especially helpful in cancer treatment, gene transfer, and vaccine creation. They have opened up new ways to target treatments that could change the way many diseases are managed. Even with these improvements, there are still problems with putting these tools to use in professional settings. To make sure that these systems can be used safely and effectively, problems like how to make them on a larger scale, how stable nanocarriers are over time, and how harmful they might be must be dealt with. To get the most out of nanocarriers, we also need to learn more about the complicated ways they interact with living things, like how the immune system works or how they build up in the body. Nanocarriers have a bright future in drug delivery, though, as long as science and technology keep getting better

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