Various Nanoparticle Used In Cancer Chemotherapy

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Abstract

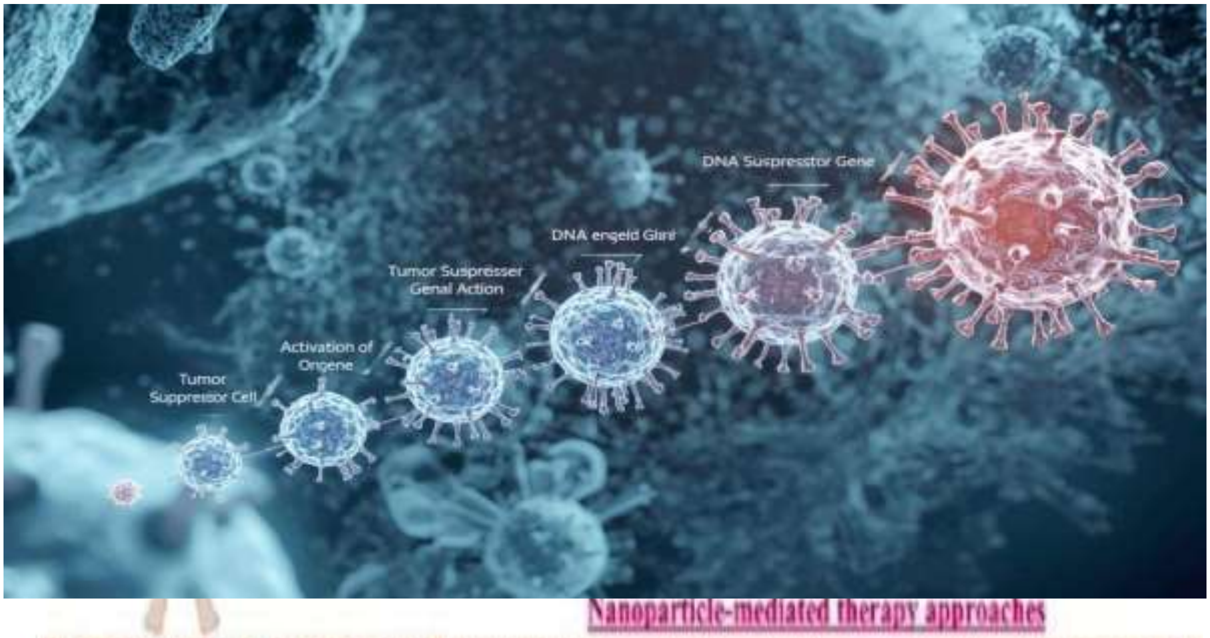
Cancer is a complex disease characterized by uncontrolled cell growth and spread, making it a leading cause of death worldwide. Nanoparticles, which are tiny particles measuring 1 to 100 nanometers, have revolutionized cancer diagnosis and treatment by leveraging their unique physicochemical properties for precise tumor targeting and reduced side effects. This has led to the emergence of nano-oncology, focusing on nanotechnology applications in cancer care. Nanoparticles enhance drug delivery specificity by preferentially accumulating in tumor tissues through the enhanced permeability and retention (EPR) effect, minimizing systemic toxicity. They serve multiple roles in cancer therapy, including carrying chemotherapy drugs, gene therapy nucleic acids, and immunomodulatory agents, as well as improving early cancer detection with sensitive imaging and biosensors. Various types of nanoparticles such as gold, iron oxide, silica, carbon nanotubes, magnetic, polymeric nanoparticles, liposomes, micelles, and dendrimers exhibit distinct properties that facilitate targeted drug delivery, imaging, therapy, and theragnostics.

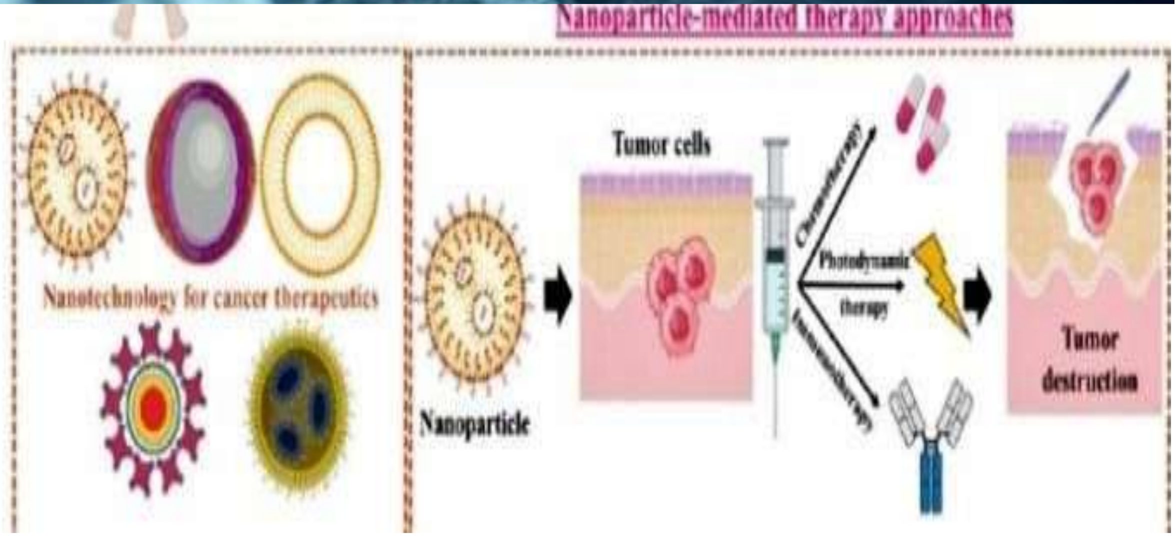
Keywords

Cancer, pathophysiology, nanotechnology , nanoparticles like gold ,silver, nanotubes, iron oxide, polymeric, polymeric micelles, liposome, Dendrimers, magnetic etc.

Introduction

Cancer is a complex disease characterized by uncontrolled cell growth and spread, making it one of the leading causes of death globally. Nanoparticles, defined as tiny particles ranging from 1 to 100 nanometers, have brought revolutionary advances in cancer diagnosis and treatment by exploiting their unique physicochemical properties that enable precise targeting and minimal side effects. This has led to the emergence of nano-oncology, a branch of cancer research focusing on nanotechnology applications .Nanoparticles have multiple roles in cancer management: they improve drug delivery specificity by preferentially accumulating in tumor tissues via the enhanced permeability and retention effect, thereby reducing systemic toxicity. They can carry chemotherapy drugs, nucleic acids for gene therapy, and immunomodulatory agents. Additionally, they enhance early cancer detection through sensitive imaging and biosensors, even detecting circulating tumor cells and molecular markers at very early stages .Overall, the integration of nanoparticles in cancer care offers improved pharmacokinetics, targeted therapy, overcoming drug resistance, and potential for simultaneous diagnosis and treatment, marking a significant leap towards personalized oncology.





Mechnism of action of Pathophysiology of cancer

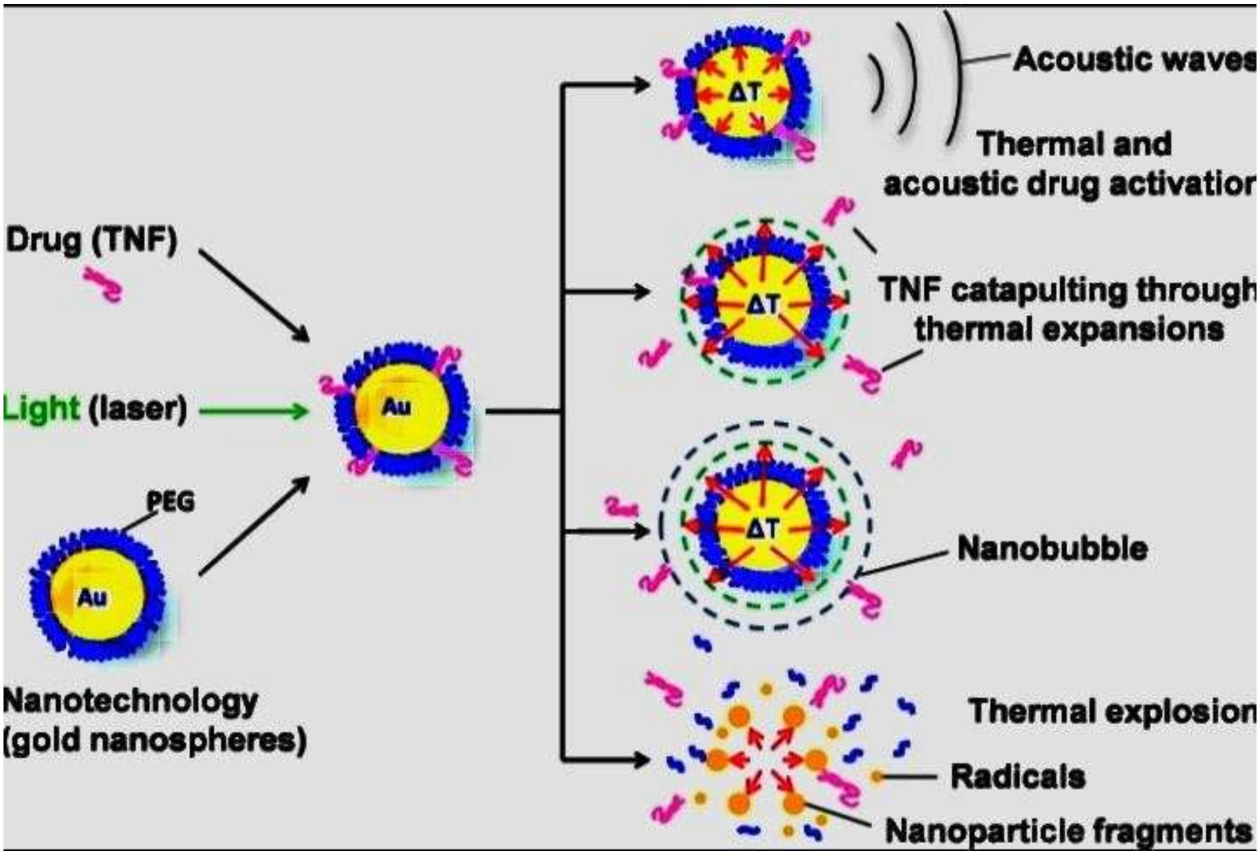
Pathophysiology

Pathophysiology

Types of nanoparticles in cancer chemotherapy

Gold nanoparticles -

Gold nanoparticles are emerging as powerful tools in the field of theragnostics—a combination of therapy and diagnostics—because of their versatility and unique properties. Their large surface area relative to their size and distinctive optical characteristics make them highly suitable for noninvasive imaging applications.These nanoparticles can be designed to carry a wide range of molecules, such as drugs, imaging agents, or targeting ligands, allowing them to perform multiple roles at once. By integrating diagnostics, targeted therapy, and real-time monitoring, gold nanoparticles help overcome many challenges of conventional medical techniques. They allow doctors to deliver both therapeutic and imaging agents to the same site, observe the treatment process, and evaluate its effectiveness immediately. Another advantage is that targeted molecular imaging with gold nanoparticles ensures that therapeutic substances accumulate mainly at the desired sites, minimizing their circulation in the bloodstream. This results in lower systemic toxicity and improved treatment safety. Due to these qualities, gold nanoparticles—composed of a gold core—provide a versatile and promising platform for biomedical uses, especially in theragnostics, photothermal therapy, and tissue imaging. Such techniques enhance disease detection efficiency while minimizing harmful effects on the immune system.Historically, the concept of theragnostics began with the use of radioactive iodine to diagnose and treat thyroid disorders, paving the way for further innovations in this area. However, several challenges remain, especially regarding their biocompatibility and toxicity. The synthesis of nanoparticles can often be inconsistent, leading to variations in size, shape, surface properties, and dosage. These inconsistencies can affect how safely and effectively the nanoparticles deliver therapeutic agents if they are not properly functionalized or administered. In cancer therapy, gold nanotechnology has shown significant promise, particularly in developing targeted drug delivery systems. Owing to their small size and unique physical properties, gold nanoparticles can penetrate cancer cells precisely, improving the accuracy of drug delivery and enhancing treatment outcomes.

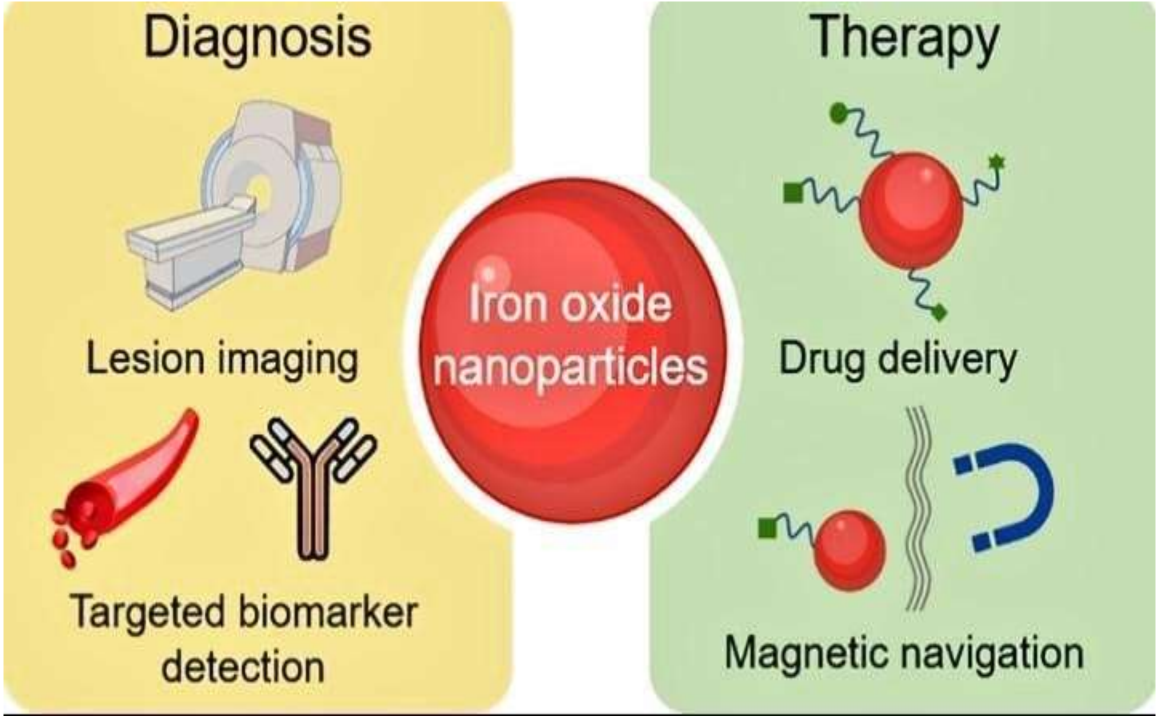


Mechnism of action of Gold Nanoparticles

Iron oxide nanoparticles –

Cancer begins with mutations or cellular changes that cause uncontrolled growth Cancer cells have unique receptors compared to normal cells, allowing targeted imaging and

treatment. Iron oxide nanoparticles can be modified with ligands (antibodies, peptides, or small molecules) to specifically bind to tumor cell receptors. These targeted nanoparticles are widely studied in both in vitro and animal models for tumor imaging. Combining iron oxide nanoparticles with antibodies like Herceptin allows precise imaging of HER2-positive breast tumors as small as 50 mg using MRI. Large antibodies pose challenges for nanoparticle conjugation due to their size, making it harder for them to move through blood vessels and reach tumor sites. The large size of antibodies also limits the number that can attach to nanoparticle surfaces and may cause non-specific binding to healthy targeted nanoparticles often fail to accumulate sufficiently in tumors, reducing imaging or treatment effectiveness. Surface modification of nanoparticles can improve their stability, biocompatibility, and tumor specificity. Stimuli-responsive nanoparticles can release drugs only in tumor environments, improving therapy and minimizing side. Iron oxide nanoparticles are used in magnetic hyperthermia therapy, where heating cancer cells under a magnetic field leads to their death They are also useful in cell-based therapy for labeling and tracking cells through MRI in regenerative medicine. iron oxide nanoparticles show great potential in cancer diagnosis, imaging, targeted drug delivery, and hyperthermia treatment, though challenges like targeting precision remain. Cancer begins with mutations or cellular changes that cause uncontrolled growth.



Mechnism of action of Iron Oxide Nanoparticles

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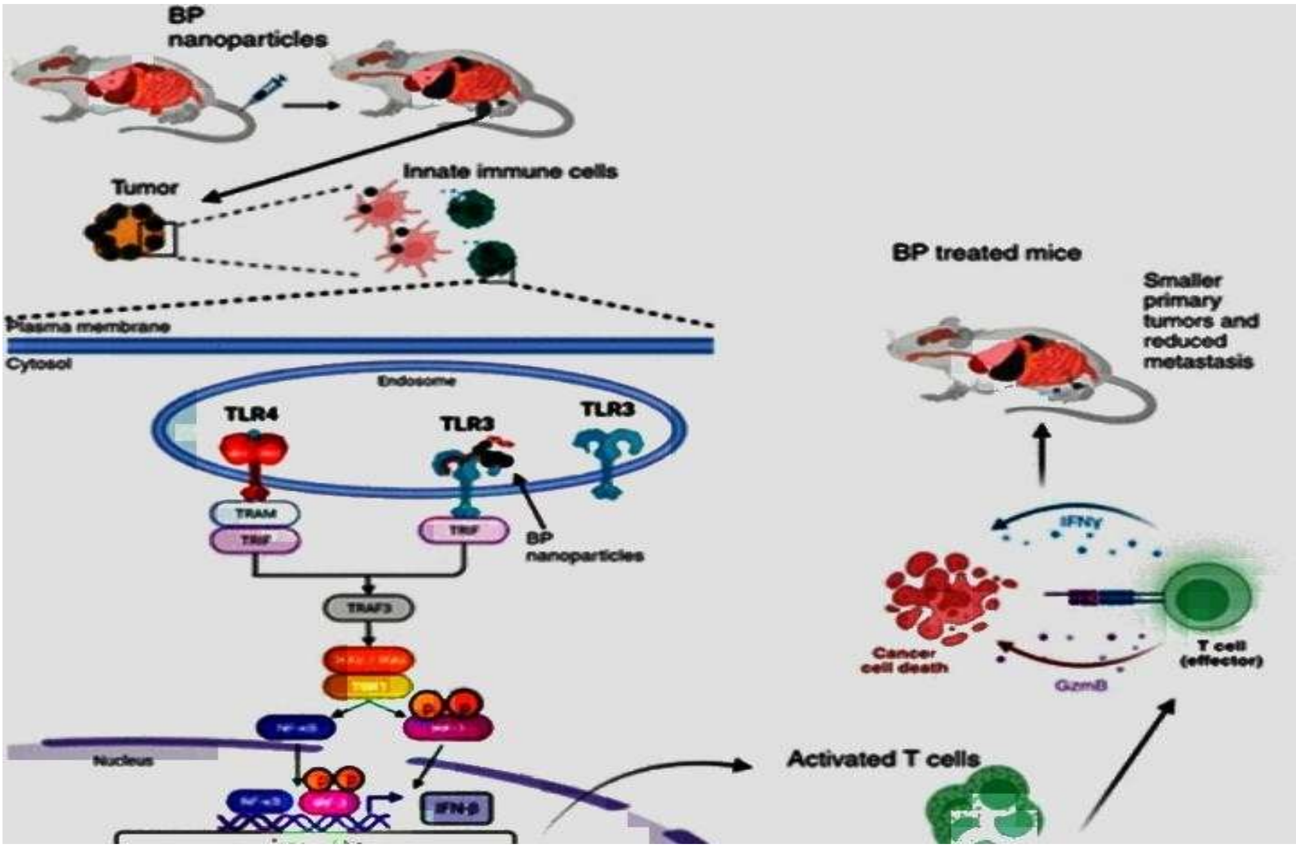
Silica nanoparticles –

Silica nanoparticles are tiny particles made from silica (silicon dioxide) that have become popular in medicine and research because they are safe, stable, and easy to control during production. Scientists can make them in different sizes and shapes, and they can also attach other useful molecules to their surface for specific purposes. Silica has long been known to be safe, even when used in surgical implants. Modern technology allows researchers to design silica nanoparticles that can carry both imaging agents and drugs — a concept known as theragnostics, which combines therapy and diagnostics in one system. During production, functional molecules such as dyes or magnetic materials can be attached to silica using chemical linkers like APS or MPS. This allows the nanoparticles to be used in optical imaging or magnetic resonance imaging (MRI).The development of mesoporous silica nanoparticles — which have tiny, adjustable pores — has made it possible to load drugs or other substances inside these pores. The surfactant (a helper chemical used in making the particles) is later removed to create open pore spaces. These nanoparticles can respond to different stimuli. For example: They can dissolve or change in acidic environments like tumor sites. They can react to slight temperature increases, releasing drugs when heated. They can respond to enzymes, light, or magnetic fields to control when and where drugs are released. Silica nanoparticles are especially useful in

cancer treatment. They can deliver chemotherapy drugs directly to tumor cells while protecting the drugs from being broken down too early by enzymes in the body. This improves how effectively the drugs work and reduces side effects. In imaging, silica nanoparticles help achieve high-resolution and real-time views of body structures through techniques such as fluorescent imaging and MRI. This helps doctors detect and monitor diseases more accurately.

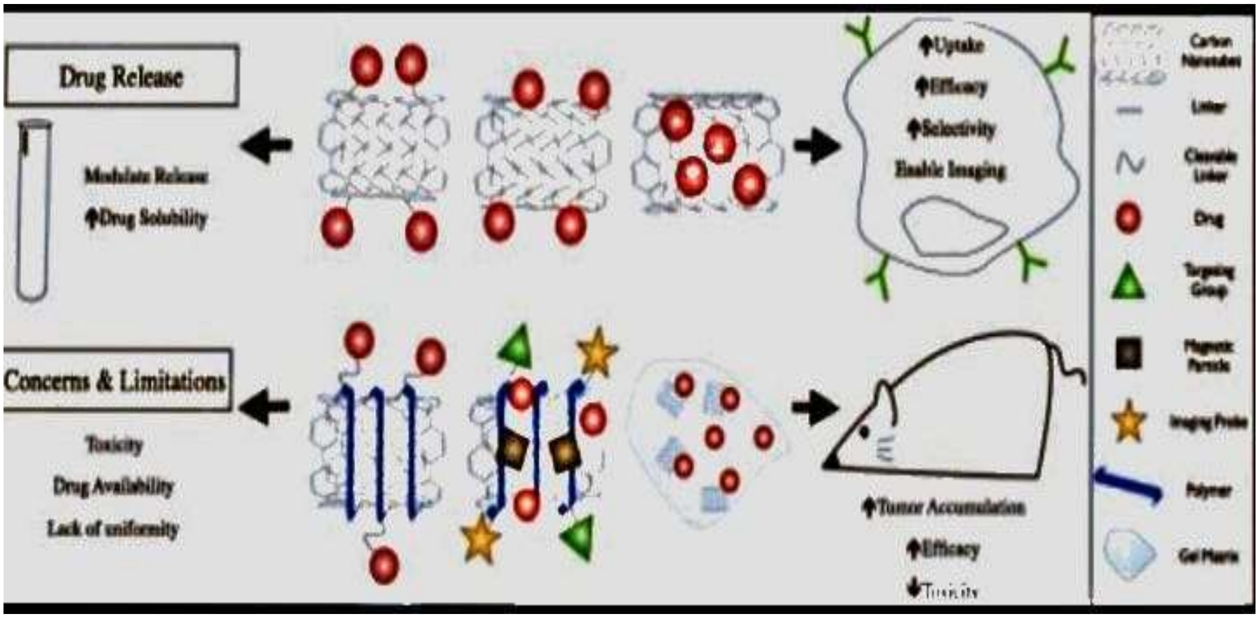


Mechnism of action of Silica nanoparticles

Carbon nanotubes -

Carbon nanotubes (CNTs) are extremely small cylindrical structures made of carbon atoms that have exceptional mechanical, electrical, and chemical properties. Their nanoscale size, large surface area, and ability to be modified make them highly useful in biomedical applications, especially in cancer diagnosis and therapy. Researchers are particularly interested in CNTs because they can carry therapeutic agents, serve as imaging tools, and even assist in regenerative medicine One major advantage of CNTs is their effectiveness as drug delivery carriers. They can transport anticancer drugs like doxorubicin or paclitaxel directly to tumor cells, which helps in maximizing the drug's impact while minimizing side effects on healthy tissues. This targeted delivery improves the efficiency of treatment and

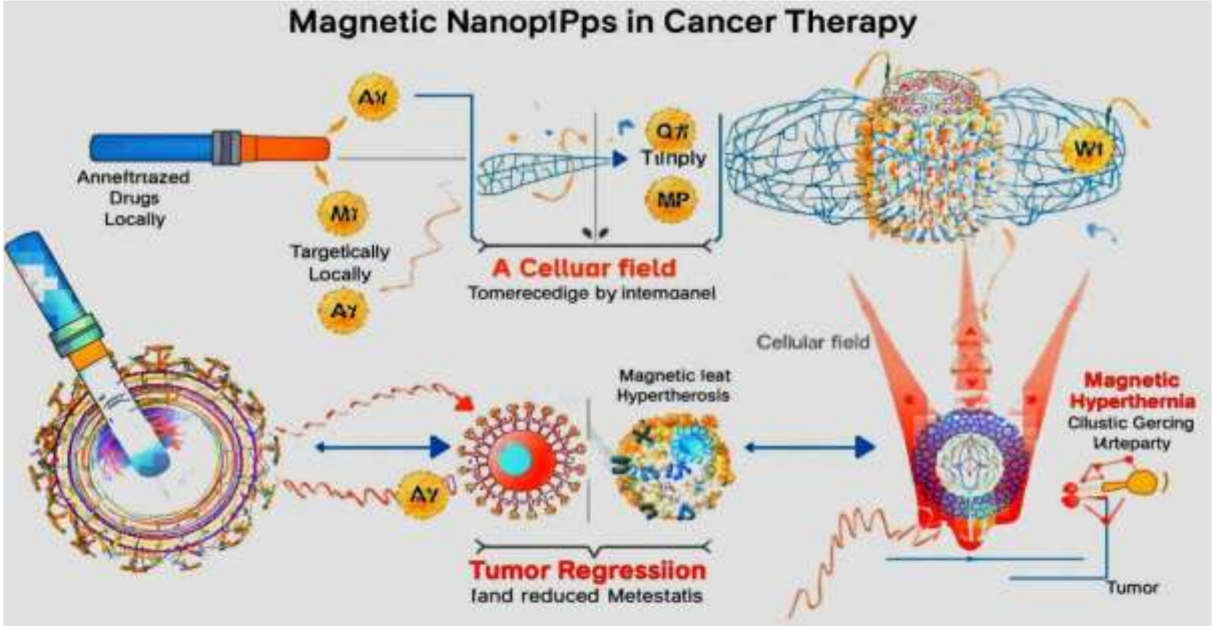
allows the use of smaller doses compared to traditional chemotherapy methods. Their hollow structure enables easy encapsulation of drugs, making them ideal for controlled and sustained release. Another advantage is their ability to act as imaging and diagnostic agents. CNTs can be functionalized with fluorescent dyes or proteins, allowing them to visualize and monitor cancer cells with high accuracy. This property is extremely valuable in surgical procedures, helping surgeons clearly distinguish between healthy and cancerous tissues during operations. As a result, CNTs improve precision in tumor removal and reduce the chances of cancer recurrence's also show great potential in gene therapy and tissue engineering. They can carry genetic material directly into target cells, supporting treatments for genetic and cancer-related diseases. In tissue regeneration, CNTs provide a scaffold that encourages the growth of stem cells into specific tissues, such as bone or nerve cells. This has significant applications in regenerative medicine, including bone marrow restoration for leukemia patients. Despite these benefits, safety and long-term effects of CNTs still require careful study. Understanding how CNTs are metabolized and cleared from the body is essential before they can be fully approved for clinical use. Overall, the advantages of CNTs—efficient drug delivery, precision imaging, gene therapy potential, and regenerative support—make them powerful tools in modern medicine with promising prospects for future healthcare innovations.



Mechnism of action of Carbon nanotubes

Magnetic nanoparticles

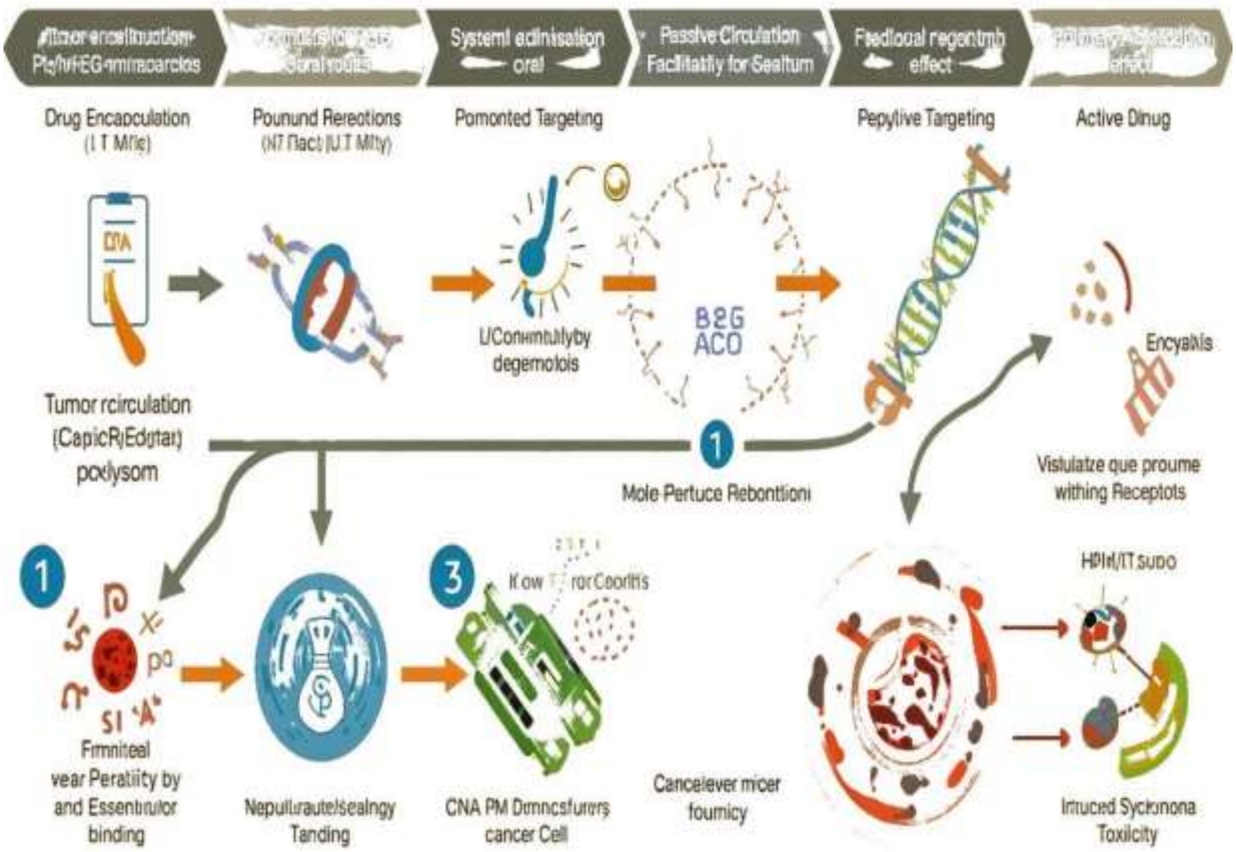
Magnetic nanoparticles (MNPs) are a special type of nanoparticle commonly made from pure metals such as iron (Fe), cobalt (Co), nickel (Ni), and certain rare earth metals, or from combinations of metals and polymers. Their use has grown significantly in the medical field, particularly in applications like cancer hyperthermia therapy, controlled drug delivery, magnetic resonance imaging (MRI), and biosensing. One of the main advantages of MNPs is that they can be guided and controlled using an external magnetic field.The biomedical performance of MNPs largely depends on characteristics such as their chemical composition, size, shape, structure, and magnetic properties. Their magnetic behavior and performance inside the body can be enhanced by applying a biocompatible surface coating. This coating helps improve their stability, biocompatibility, and ability to attach to specific biological targets. It also allows for chemical functionalization, making the MNPs capable of performing multiple functions at once — for example, combining heat-based therapy (hyperthermia) with drug delivery or enabling different imaging techniques simultaneously. The concept of hyperthermia therapy originated in the 19th century when scientists discovered that elevated body temperature could suppress tumor growth. Research later showed that cancer cells are more sensitive than normal cells to temperatures between 42– 45°C. While healthy cells can briefly withstand these temperatures, cancer cells tend to die through a process called apoptosis. Therefore, maintaining this thermal condition in tumor tissues offers an effective way to treat cancer without causing major damage to healthy tissues.



Mechnism of action of Magnetic nanoparticles

Polymeric nanoparticles

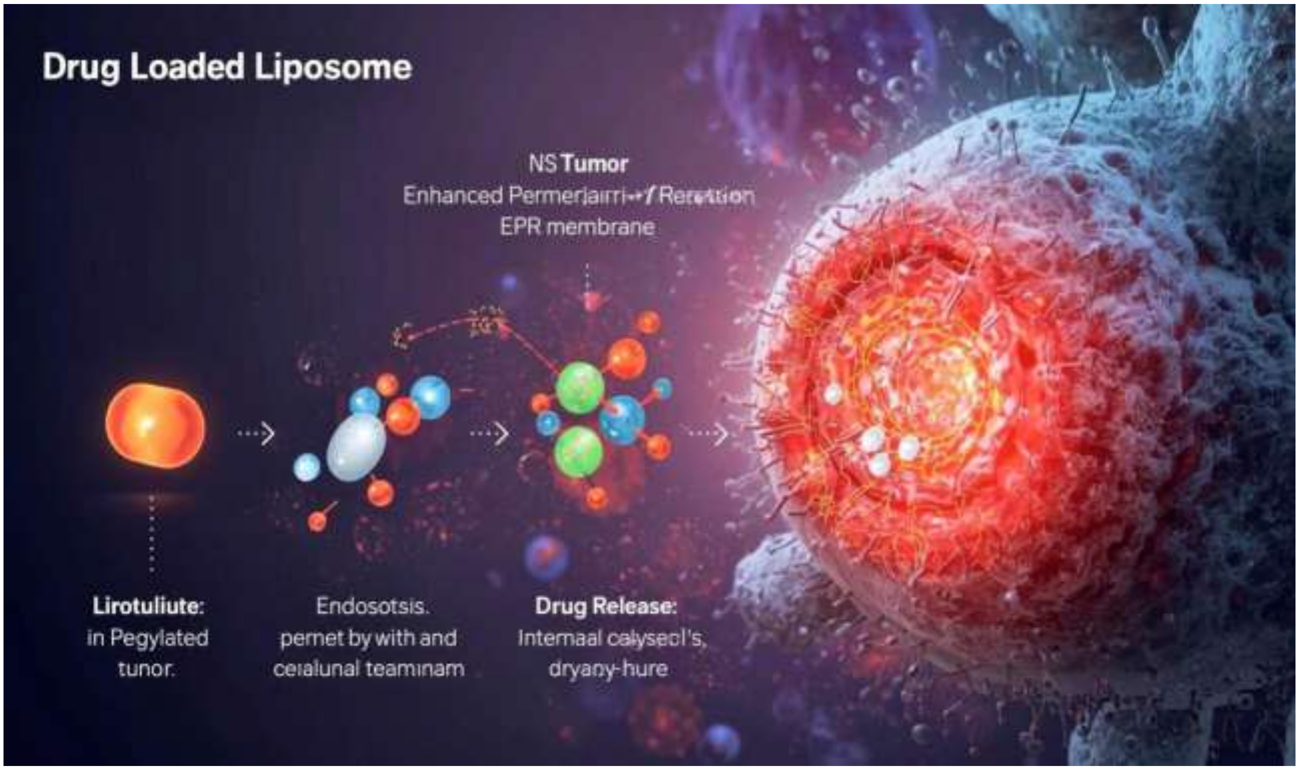
Polymeric nanoparticles are increasingly important for delivering cancer drugs in a controlled manner. These anticancer drugs can be either attached to or enclosed within polymer-based Nano carriers, collectively known as polymeric nanomedicine. Such nanomedicine have demonstrated the ability to provide sustained drug release, lower toxicity, and improve drug retention in tumors. However, very few drug delivery systems using these nanoparticles have successfully met clinical requirements so far, meaning further research and development is necessary. This study reviews the current progress in cancer drug-loading methods, summarizing findings from various published works that showcase innovative designs and applications. It covers a wide range of nanoparticle architectures, such as micelles, liposomes, dendrites, polymerases, hydrogels, and metal–organic frameworks, which could help create effective polymeric nanoparticles for diverse therapeutic goals.



Mechnism of action of Polymeric nanoparticles

Liposome

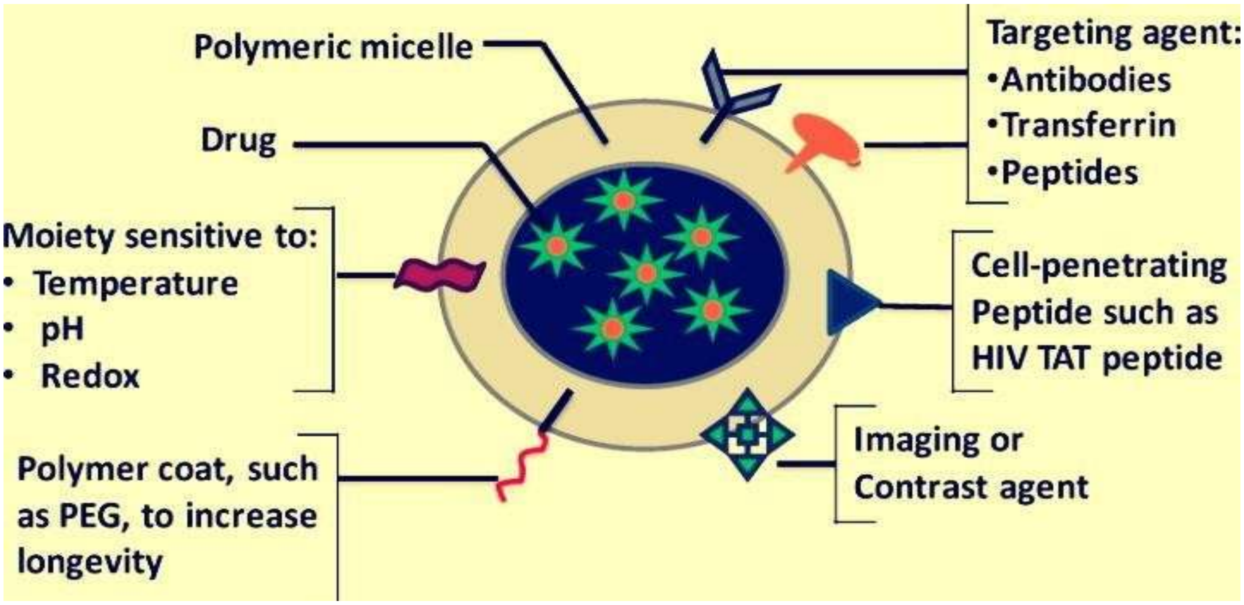
Many chemotherapy drugs have reduced effectiveness because they are quickly broken down in the body, can cause harmful side effects, and may lead to drug resistance. To address these issues, researchers use nanoparticles such as liposomes to make cancer treatments more effective. Liposomes offer several benefits: they improve how long and how well the drug stays active in the body, circulate in the bloodstream for longer periods, and naturally accumulate in tumors and inflamed tissues due to the enhanced permeability and retention (EPR) effect. They also help lower the harmful side effects of the drug, improve the drug's solubility, and allow for slow, controlled release. However, despite these advantages, nanoparticles like liposomes can still cause some toxicity and often lack precise targeting ability.



Mechnism of action of Liposome

Polymeric micelles

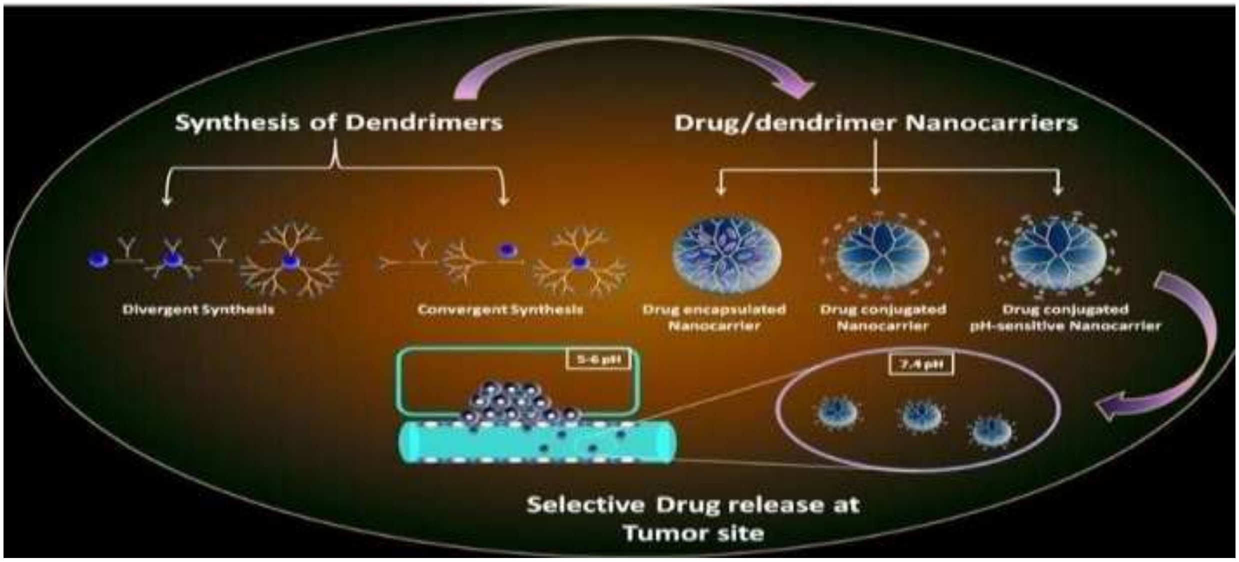
The article explains that polymeric micelles are a highly effective method for delivering cancer drugs that are poorly soluble in water. These micelles are very small (10–100 nm) and have a hydrophilic shell, usually made of PEG (polyethylene glycol), which helps them circulate longer in the bloodstream and accumulate more effectively in tumors. This accumulation occurs through the enhanced permeability and retention (EPR) effect, where drugs passively enter tumors through their leaky blood vessels.There are different types of micelles depending on how they form, such as amphiphilic micelles (made from molecules with both hydrophobic and hydrophilic parts), polyion- complex micelles, and micelles formed through metal complexation. When placed in water, amphiphilic molecules naturally self-assemble into a core– shell structure, with the hydrophobic core holding the drug and the hydrophilic shell preventing unwanted interactions in the blood.Micelles can have different shapes—like spheres, rods, or worm-like forms—and shape influences how long they stay in circulation. For example, worm-like micelles can circulate up to ten times longer than spherical ones. PEG is the most common hydrophilic material used because it is safe, neutral, and water-soluble, but other polymers like PVP or pNIPAM are also used.



Mechnism of action of Polymeric micelles

Dendrimers

Dendrimers are highly branched polymeric structures made up of three main parts: a core, branches, and terminal functional groups. The core serves as the central component of the Dendrimers and can be an atom or molecule that has at least two identical chemical functional groups.The branching of dendrimers defines their "generation." A first-generation dendrimer has one layer of branches, while a fifth-generation dendrimer has five branching layers. As the number of generations increases, the number of surface functional groups also increases, enabling more interactions with biologically active substances. Because of their structure, dendrimers act as nanoparticle templates and stabilizers, making them useful in drug delivery. Their structural diversity allows them to carry different pharmacologically active compounds. Moreover, their size, shape, branch length, surface properties, and internal structure can be precisely controlled, which makes them ideal for various biomedical applications. Dendrimers have regulated and tunable sizes, can interact with cell membranes and drug molecules, and have unique internal cavities that can encapsulate drugs through electrostatic and hydrophobic interactions. The multiple reactive groups on their surface (a feature known as polyvalency) allow them to attach to various biological receptors, making them effective in targeted drug delivery.



Mechnism of action of Dendrimers

Conclusion

Nanotechnology has ushered in a new era in cancer treatment by utilizing various types of nanoparticles, both organic and inorganic, which are widely applied in clinical cancer therapies. Nanoparticle-based drug delivery systems improve pharmacokinetics, biocompatibility, tumor targeting, and stability, while reducing systemic toxicity and overcoming drug resistance. These nanoparticles enable enhanced chemotherapy, targeted therapy, radiotherapy, hyperthermia, and gene therapy with greater efficacy and safety compared to conventional treatments. The design of nanoparticle carriers allows for combination therapies that address multiple drug resistance mechanisms. Ongoing research is focusing on hybrid nanoparticles with improved delivery properties and cancer-cell-specific targeting, as well as better understanding the interactions between nanoparticles and the immune system. Despite promising advances, challenges remain related to the safety, tolerance, and clinical translation of nanoparticle-based therapies. Future studies on tumor microenvironment interactions and immune modulation will further optimize nanoparticle design to enhance therapeutic outcomes in cancer treatment.

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