Available online on 15.09.2026 at http://jddtonline.info

Journal of Drug Delivery and Therapeutics

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Review Article

Nanoparticles in cancer: A highly Effective method for targeted drug delivery

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Article Info:

Article History:

Received 17 June 2026
Reviewed 06 Aug 2026
Accepted 28 Aug 2026
Published 15 Sep 2026

Cite this article as:

Patil G, Parmar K, Rana K, Nanoparticles in cancer: A highly Effective method for targeted drug delivery, Journal of Drug Delivery and Therapeutics. 2026; 16(9):194-203 *DOI:* https://doi.org/10.22270/jddt.v16i9.7957

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Abstract

Background: Cancer remains one of the leading causes of mortality worldwide. Although conventional chemotherapy remains an important component of cancer treatment, its clinical effectiveness is often limited by poor tumour selectivity, systemic toxicity, multidrug resistance, and adverse effects. Nanoparticle-based drug delivery systems have emerged as promising approaches for improving the targeted delivery of anticancer agents while reducing exposure of healthy tissues. Objective: This review provides an overview of nanoparticle-based targeted drug delivery in cancer therapy, with emphasis on passive and active targeting mechanisms, major nanoparticle platforms, therapeutic applications, current challenges, and prospects for clinical translation. Findings: Nanoparticle systems including liposomes, polymeric nanoparticles, dendrimers, solid lipid nanoparticles, metallic nanoparticles, iron oxide nanoparticles, quantum dots, and carbon dots demonstrate potential for improving drug delivery, cellular uptake, imaging, and combined therapeutic approaches. Passive targeting is largely associated with the enhanced permeability and retention effect, whereas active targeting uses ligands to facilitate receptor-mediated cellular uptake. However, variations in tumour biology, nanoparticle properties, toxicity, manufacturing, and regulatory requirements remain important barriers to clinical translation.

Keywords: Nanoparticles; Targeted Drug Delivery; Cancer Therapy; Nanomedicine; Tumor Targeting; Liposomes; Polymeric Nanoparticles; Enhanced Permeability and Retention (EPR) Effect

INTRODUCTION:

Cancer is one of the most significant global health challenges and remains a leading cause of death worldwide. Despite remarkable progress in cancer diagnosis and treatment, the increasing incidence of cancer continues to place a substantial burden on healthcare systems. Conventional treatment approaches, including surgery, chemotherapy, radiotherapy, immunotherapy, and hormone therapy, have improved patient survival; however, chemotherapy remains the primary treatment for many solid and hematological malignancies. Unfortunately, conventional chemotherapeutic drugs lack tumour specificity and distribute throughout the body, often causing severe systemic toxicity, undesirable adverse effects, multidrug resistance, and damage to healthy tissues. These limitations frequently reduce therapeutic efficacy and negatively affect patients' quality of life.

Advances in nanotechnology have opened new opportunities for improving cancer treatment through targeted drug delivery. Nanoparticles are engineered carriers, generally ranging from 1 to 100 nm in size, that can transport therapeutic agents directly to tumour tissues while protecting the drug from premature degradation. Their unique physicochemical properties, including a large surface-area-to-volume ratio, tunable surface chemistry, and controlled drug-release capabilities, enable improved drug stability, enhanced bioavailability, prolonged circulation time, and reduced off-target toxicity compared with conventional drug delivery systems.

Targeted delivery of anticancer drugs can be achieved through two principal approaches: passive targeting and active targeting. Passive targeting relies on the enhanced permeability and retention (EPR) effect, which allows nanoparticles to accumulate preferentially in tumour tissue because of abnormal tumour vasculature and impaired lymphatic drainage. However, the effectiveness of the EPR effect varies considerably among tumour types and individual patients, limiting its clinical reliability. Active targeting involves functionalizing nanoparticle surfaces with specific ligands such as antibodies, peptides, aptamers, folate, or carbohydrates that recognize receptors overexpressed on cancer cells. This strategy enhances cellular uptake and improves treatment specificity but does not always guarantee greater accumulation within the tumour.

A wide variety of nanoparticle platforms—including liposomes, polymeric nanoparticles, dendrimers, micelles, solid lipid nanoparticles, metallic nanoparticles, silica nanoparticles, iron oxide nanoparticles, quantum dots, and carbon-based nanomaterials—have been investigated for cancer therapy. Several formulations have progressed to clinical use, whereas many others remain in preclinical or clinical development because of challenges related to biological interactions, protein-corona formation, large-scale manufacturing, long-term safety, regulatory approval, and clinical translation.

Although numerous review articles have discussed nanoparticle-mediated drug delivery, continuous advances in nanomedicine and the growing understanding of tumour biology require updated evidence-based evaluations. Therefore, this review aims to comprehensively discuss the principles of nanoparticle-based targeted drug delivery in cancer therapy, describe the major classes of nanoparticles, evaluate their therapeutic applications, examine current challenges affecting clinical translation, and highlight future directions for the development of safer and more effective nanomedicines.

LITERATURE SEARCH METHODOLOGY

A comprehensive literature search was conducted to identify relevant studies on nanoparticle-based targeted drug delivery in cancer therapy. Electronic databases, including PubMed, Google Scholar, ScienceDirect, and Scopus, were searched for peer-reviewed articles published between January 2015 and June 2026.

The search strategy incorporated combinations of the following keywords: “nanoparticles”, “cancer”, “targeted drug delivery”, “nanomedicine”, “passive targeting”, “active targeting”, “liposomes”, “polymeric nanoparticles”, “solid lipid nanoparticles”, “dendrimers”, “metallic nanoparticles”, “quantum dots”, and “drug delivery systems.” Boolean operators (AND, OR) were used to refine the search and improve the relevance of the retrieved studies.

Original research articles, systematic reviews, review articles, clinical studies, and authoritative reports published in the English language were considered for inclusion. Articles with incomplete data, duplicate publications, conference abstracts lacking sufficient scientific information, and non-English publications were excluded.

The retrieved articles were screened based on their titles, abstracts, and full texts to evaluate their relevance to the objectives of this review. Preference was given to recent publications describing nanoparticle design, mechanisms of targeted drug delivery, therapeutic applications, clinical translation, and current challenges associated with nanomedicine in cancer therapy.

1. MECHANISM OF TARGETED DRUG DELIVERY USING NANOPARTICLES. [1,2]

The area of nanotechnology develops nanoscale sized materials that consist of natural, synthetic polymers, lipids or metallic materials. The first action of nanoparticles for use in drug delivery was based on a passive targeting mechanism that aimed to increase efficiency over traditional- free drug formulations. This approach has been introduced that consist of active targeting through the specific ligands to eliminate drug delivery to targeted sites.

1.1 How nanoparticles target tumour cells. [1,3,4]

For specific and efficient targeted drug delivery of nanoparticles is that nanoparticles must be enter in tumour cells. The mechanism of nanoparticles - mediated targeted drug delivery involves several key steps like circulation in blood stream, accumulation at the tumour site, penetration through the vascular wall and uptake by tumour cells, which is very useful in drug dosage circulation. The drug dose can be calculated by multiply the nanoparticles in the tumour by the drug amount per nanoparticles, for calculation of drug dose, ‘The total amount of drug delivered to the tumor depends on the number of nanoparticles accumulated in the tumor and the drug loading capacity of each nanoparticle’.[2,4] The nanoparticle must cross the tumour blood vessel for high delivery. The nanoparticle that escapes the RES (Reticuloendothelial system) organs they have the potential to cross the tumour endothelium to the microenvironment. It was hypothesised that nanoparticles enter solid tumour through the gaps between the blood vessels. The inter endothelial gaps are formed when cancerous tissue undergoes rapid angiogenesis. The vessels grow irregularly and rapidly. Tight junctions do not fully form & forms these gaps. Factors such as particle size, surface charge and hydrophobicity also influence how efficiently nanoparticles cross tumour barriers and reach their target cells.

1.2 Passive targeting vs Active targeting.

Passive targeting [3,4]

Passive targeting is one of the earliest and most widely investigated approaches for nanoparticle-mediated drug delivery in cancer therapy. It primarily depends on the Enhanced Permeability and Retention (EPR) effect, a phenomenon in which nanoparticles preferentially accumulate within tumour tissues because of the abnormal structure of tumour blood vessels and impaired lymphatic drainage. Rapid tumour growth results in the formation of highly permeable and irregular blood vessels with large endothelial gaps, allowing nanoparticles to extravasate into the tumour microenvironment. In addition, the inefficient lymphatic drainage of tumour tissue promotes prolonged retention of nanoparticles, thereby increasing the local concentration of anticancer drugs.

The effectiveness of passive targeting is influenced by several nanoparticle characteristics, including particle size, surface charge, shape, circulation time, and surface modification. Nanoparticles with prolonged blood circulation, particularly those coated with hydrophilic polymers such as polyethylene glycol (PEG), have a greater probability of reaching tumour tissues through the EPR effect while reducing rapid clearance by the mononuclear phagocyte system.

Although the EPR effect has shown promising results in many experimental studies, its clinical application remains inconsistent. The extent of nanoparticle accumulation varies considerably among different tumour types and even among patients with the same type of cancer. Factors such as tumour vascularization, stromal density, interstitial fluid pressure, tumour location, and biological heterogeneity can significantly influence the efficiency of passive targeting. Consequently, the EPR effect should not be regarded as a universally reliable mechanism for tumour-specific drug delivery.

Despite these limitations, passive targeting continues to play an important role in nanomedicine and has contributed to the development of several clinically approved nanoparticle formulations. Ongoing research aims to improve passive targeting by optimizing nanoparticle design, enhancing circulation time, and combining passive targeting with active targeting strategies to achieve improved therapeutic outcomes.

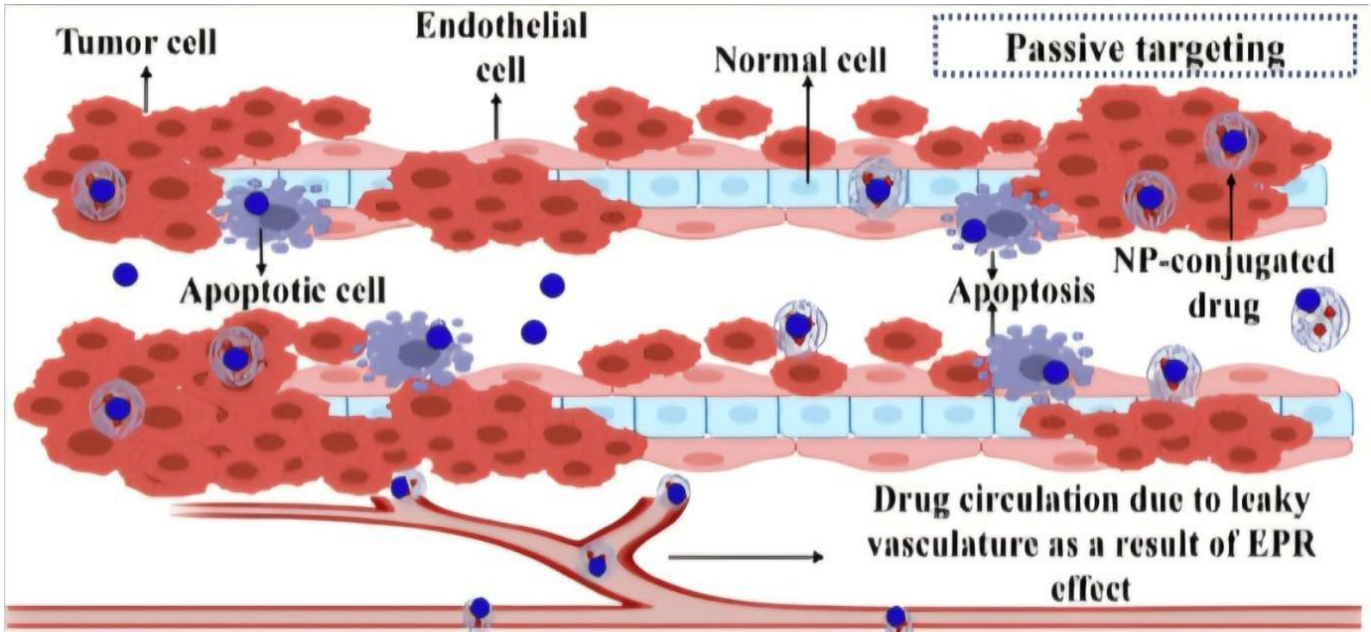

Fig.1 Passive targeting of nanoparticles through the EPR effect. Nanoparticles accumulate in tumor tissue due to leaky vasculature and poor lymphatic drainage, leading to enhanced permeability and retention at the tumor site. [5]

Active targeting [2]

Active targeting is an advanced strategy in nanoparticle-mediated drug delivery that enhances the selective interaction of nanoparticles with cancer cells. Unlike passive targeting, which depends on the Enhanced Permeability and Retention (EPR) effect, active targeting is achieved by functionalizing the nanoparticle surface with specific ligands that recognize and bind to receptors overexpressed on tumour cells. Commonly used targeting ligands include monoclonal antibodies, peptides, aptamers, folate, and carbohydrates, each offering different levels of receptor specificity and targeting efficiency.

Following receptor binding, the nanoparticle–ligand complex undergoes receptor-mediated endocytosis, resulting in improved cellular uptake of the therapeutic agent by cancer cells. However, it is important to distinguish improved cellular uptake from increased whole-tumour accumulation. Active targeting primarily enhances the internalization of nanoparticles by target cells after they have reached the tumour site, but it does not necessarily increase the overall quantity of nanoparticles delivered to the tumour. Therefore, active targeting is often combined with passive targeting to maximize therapeutic efficacy.

Different targeting ligands possess distinct advantages and limitations. Monoclonal antibodies provide high receptor specificity but may exhibit limited tissue penetration and higher immunogenicity. Peptides are smaller in size, demonstrate good tumour penetration, and generally have lower immunogenicity, although they are more susceptible to enzymatic degradation. Aptamers offer high binding affinity and low immunogenicity but may have limited in vivo stability without chemical modification. Folate is widely used because folate receptors are overexpressed in several cancers, while carbohydrate-based ligands target lectin receptors involved in tumour progression and cell adhesion.

Although active targeting has significantly improved the precision of nanoparticle-based drug delivery, several challenges remain, including receptor heterogeneity, variable receptor expression among patients, ligand stability, immune recognition, large-scale manufacturing, and regulatory approval. Continued research is focused on developing multifunctional and stimuli-responsive nanoparticles to improve targeting efficiency and facilitate successful clinical translation.

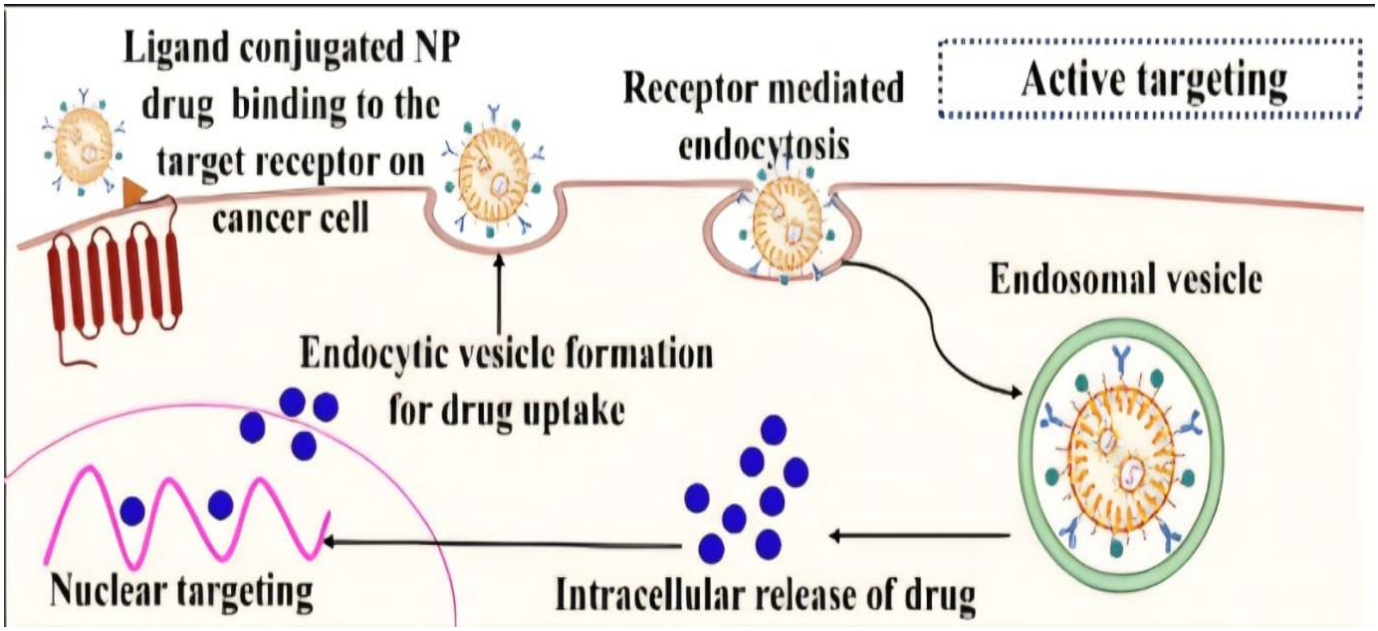

Fig. 2 Active targeting of nanoparticles via ligand–receptor interaction. Ligand-conjugated nanoparticles bind to specific receptors on cancer cells and are internalized through receptor-mediated endocytosis, followed by intracellular drug release for targeted therapy. [5]

2. CLASSIFICATION OF NANOPARTICLES IN CANCER TARGETED DRUG DELIVERY.

2.1 classification [5,6]

- Organic nanoparticles
- Inorganic nanoparticles

Nanoparticles used for targeted drug delivery in cancer therapy can be classified based on their composition, structural characteristics, and physicochemical properties. Each nanoparticle system possesses unique advantages and limitations that influence its drug-loading capacity, biocompatibility, stability, targeting efficiency, and clinical applications. Rather than simply classifying nanoparticles as organic and inorganic, a more systematic classification provides a clearer understanding of their therapeutic roles.

Organic nanoparticles include liposomes, polymeric nanoparticles, dendrimers, polymeric micelles, and solid lipid nanoparticles (SLNs). These systems are generally biodegradable, biocompatible, and capable of encapsulating both hydrophilic and hydrophobic drugs, making them suitable for controlled and targeted drug delivery.

Inorganic nanoparticles comprise gold nanoparticles, silver nanoparticles, iron oxide nanoparticles, silica nanoparticles, quantum dots, and carbon-based nanomaterials, including carbon nanotubes and graphene derivatives. These nanoparticles possess unique optical, magnetic, electrical, and physicochemical properties that enable their application in drug delivery, molecular imaging, photothermal therapy, and theranostic approaches.

The selection of an appropriate nanoparticle platform depends on several factors, including the physicochemical properties of the therapeutic agent, the target tissue, drug-release characteristics, biocompatibility, toxicity profile, and intended clinical application. A systematic understanding of different nanoparticle systems is therefore essential for designing effective and safe targeted drug delivery strategies for cancer treatment.

2.2 Organic nanoparticles [6,7]

Organic nanoparticles can be defined as solid particles made up of natural or synthetic organic molecules. Generally, they are ranging in diameter from 10-100 nm, but also, they can reach up to 1000 nm. Organic nanoparticles have some important characteristics such as lower toxicity and high biodegradability. They are composed of mainly natural or synthetic polymers phospholipids and surfactants. Some certain properties like size, shape and surface morphology also hold the importance in determining the therapeutic effectiveness of organic nanoparticle.

Overall, the organic nanoparticles also give rise to promising opportunities for further research and development.

2.2.1 Polymeric nanoparticles [8,9,10]

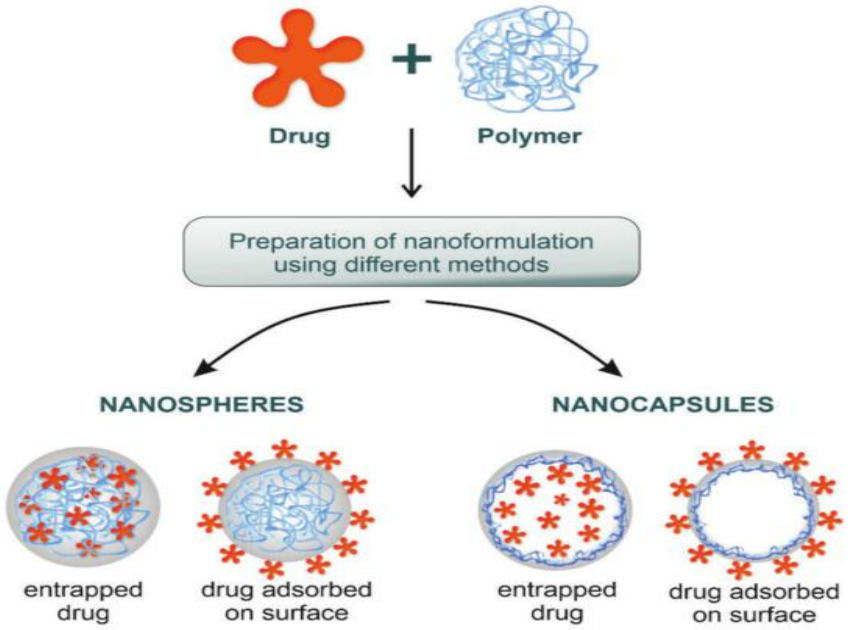

Fig.3 Preparation of polymeric nanoparticles (nanospheres and nano capsules). Drugs can be either entrapped within the polymer matrix or adsorbed on the surface depending on the formulation method used. [10]

Polymeric nanoparticles are nanocarriers composed of natural or synthetic polymers. Common synthetic polymers include poly(lactic-co-glycolic acid) (PLGA), polyethylene glycol (PEG), polyethyleneimine (PEI), and poly-L-lysine (PLL), whereas chitosan is one of the most widely used natural polymers. Dendrimers, although polymeric in nature, are highly branched polymeric nanostructures and are generally classified separately because of their unique architecture and physicochemical properties.

The typical size of polymeric nanoparticles ranges from 1 to 1000 nm. Based on their structural organization, they are classified into nanospheres and Nano capsules. Nanospheres are matrix-type systems in which the drug is uniformly dispersed or adsorbed throughout the polymer matrix. In contrast, Nano capsules are reservoir-type systems in which the drug is confined within a central core surrounded by a polymeric shell. These structural differences influence drug loading, release characteristics, stability, and therapeutic performance.

Polymeric nanoparticles offer several advantages, including controlled and sustained drug release, improved drug stability, enhanced bioavailability, biocompatibility, and the potential for surface modification to achieve targeted drug delivery. Consequently, they have been extensively investigated for delivering anticancer agents while reducing systemic toxicity and improving therapeutic efficacy.

2.2.2 Liposomes [12,13,14]

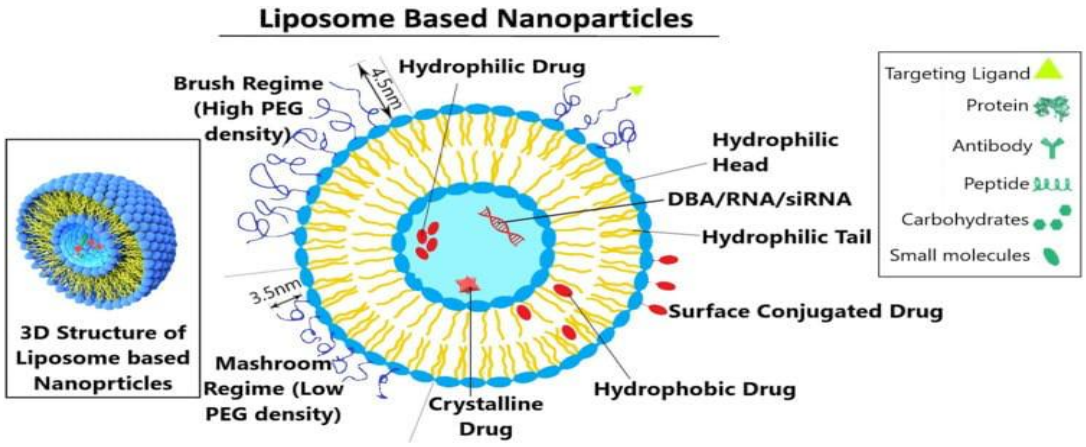

Fig. 4 Structure and components of liposome-based nanoparticles. Liposomes consist of a phospholipid bilayer that can encapsulate both hydrophilic and hydrophobic drugs, carry genetic materials, and allow surface conjugation of targeting ligands for site-specific drug delivery. [11]

Liposomes are spherical vesicular nanocarriers mainly composed of phospholipids. These phospholipids are amphiphilic molecules consisting of a hydrophilic head and a hydrophobic (lipophilic) tail. They can be synthesized either entirely or partially from natural sources. Liposomes generally range in size from 20 nm to 2.5 µm and may consist of one or multiple concentric or non-concentric phospholipid bilayers surrounding an aqueous core. The size of the vesicles and the number of bilayers is important factors that influence drug encapsulation efficiency, circulation half-life, and clearance from the body.

Compared with conventional drug delivery systems, liposomes exhibit several advantages, including excellent biocompatibility, biodegradability, low toxicity, easy surface modification, high drug-loading capacity, and protection of encapsulated drugs from premature degradation. Owing to their unique structure, liposomes can encapsulate hydrophilic drugs within the aqueous core and hydrophobic drugs within the phospholipid bilayer, making them versatile carriers for anticancer drug delivery. Surface modification with polyethylene glycol (PEG) can further prolong blood circulation by reducing recognition and clearance by the mononuclear phagocyte system, while conjugation with specific ligands enables active targeting of tumour cells.

Doxil® (pegylated liposomal doxorubicin) was the first liposomal formulation approved by the U.S. Food and Drug Administration (FDA) in 1995 for cancer treatment. Since then, several liposomal formulations have been developed to improve therapeutic efficacy while reducing the systemic toxicity associated with conventional chemotherapy. Despite these advantages, liposomes still face challenges such as drug leakage during storage, limited stability, manufacturing complexity, and high production costs, which continue to be areas of active research

2.2.3 Dendrimers [15,16]

Dendrimers are highly branched, three-dimensional polymeric nanostructures synthesized from a central core through repeated, stepwise chemical reactions, resulting in a well-defined spherical architecture. Unlike conventional synthetic polymers, dendrimers possess a highly controlled and symmetrical structure, making them suitable for targeted drug delivery applications.

A dendrimer consists of three primary architectural components:

1. Core: The central atom or molecule from which the dendrimer originates.

2. Generations: Repeated branched layers extending outward from the core, determining the size and molecular weight of the dendrimer.

3. Terminal Functional Groups: Surface functional groups that can be modified for drug conjugation, targeted delivery, or enhanced biocompatibility.

Lower-generation dendrimers (G0–G2) exhibit an open and asymmetrical structure, whereas higher-generation dendrimers (G4 and above) become more compact and globular because of extensive branching. At very high generations, further growth is limited by the starburst effect, in which steric crowding and insufficient space at the molecular periphery prevent the addition of new branches.

Dendrimers possess several advantages, including high drug-loading capacity, controlled drug release, excellent surface functionalization, and the ability to carry both therapeutic and diagnostic agents. These unique characteristics make them promising nanocarriers for targeted cancer therapy. However, concerns regarding cytotoxicity, complex synthesis, and high production costs continue to limit their widespread clinical application.

2.2.4 Solid lipid nanoparticles (SLNs) [17]

Solid lipid nanoparticles (SLNs) have emerged as a promising nanocarrier system for cancer therapy because they combine the advantages of lipid-based drug delivery with improved stability and controlled drug release. Compared with conventional chemotherapy, SLNs have demonstrated enhanced drug delivery and reduced systemic toxicity in several preclinical studies.

SLNs are colloidal particles with a typical size ranging from 50 to 1000 nm. They consist of a matrix of solid lipids, which remain solid at both room and body temperature, stabilized by surfactants (tensioactive agents). The lipid matrix enables the incorporation of drug molecules either within the lipid core or adsorbed onto the particle surface, depending on the physicochemical properties of the drug.

SLNs offer several advantages, including high biocompatibility, protection of drugs from degradation, controlled drug release, improved bioavailability, and the potential for surface modification to achieve targeted drug delivery. These properties make them suitable carriers for both hydrophilic and lipophilic anticancer agents. However, limitations such as limited drug-loading capacity, drug expulsion during storage due to lipid crystallization, and challenges in large-scale production continue to restrict their widespread clinical application.

2.3 Inorganic nanoparticles [18]

Inorganic nanoparticles for drug delivery in cancer treatment offer many potential advantages because they can maximise therapeutic effect through targeting ligands while minimizing off-target side effects through drug absorption & infiltration. Although inorganic nanoparticle was introduced as drug carriers, they have emerged as having the capacity for combined therapeutic cytotoxicity, suppression of oncogenes and cancer cell signalling pathway inhibition. The most promising advanced strategies for cancer therapy are as synergistic platforms for RNA interference (siRNA, miRNA, shRNA) and as synergistic drug delivery agents for the inhibition of cancer cell signalling pathway.

2.3.1 Gold nanoparticles (AuNPs) [19,20,21,22,23]

Gold nanoparticles (GNPs) are emerging as promising nanomaterials for cancer diagnosis and therapy because of their unique optical, electronic, and physicochemical properties. They are widely investigated as drug carriers, imaging agents, and therapeutic platforms for targeted cancer treatment. The most common oxidation states of gold are +1 and +3, while the nanoscale properties of GNPs make them particularly suitable for biomedical applications.

Gold nanoparticles are not a recent discovery. In the 19th century, Michael Faraday published one of the first scientific reports on the synthesis of gold nanoparticles. During the late 20th century, advanced techniques such as transmission electron microscopy (TEM) and atomic force microscopy (AFM) enabled direct visualization of GNPs and facilitated precise control over their size, shape, and surface characteristics.

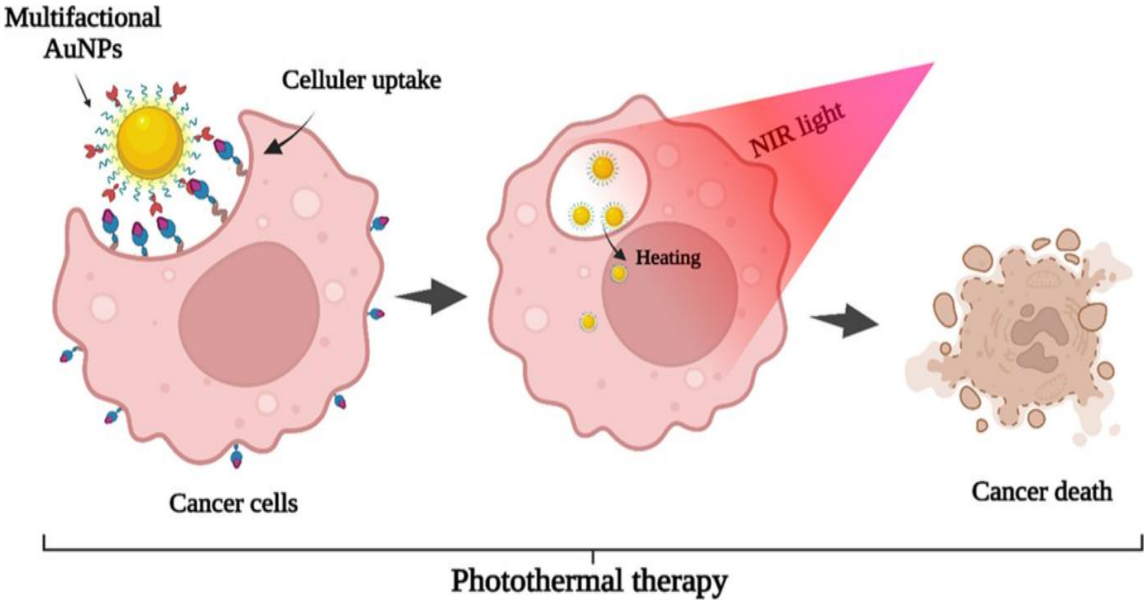

Fig.5 Photothermal therapy using multifunctional gold nanoparticles (AuNPs). Gold nanoparticles absorb near-infrared (NIR) light and convert it into heat, resulting in localized tumor cell destruction after cellular uptake. [23]

Surface functionalization of GNPs is currently an area of extensive research. Gold nanoparticles can be conjugated with polyethylene glycol (PEG), antibodies, peptides, or other targeting ligands to improve biocompatibility, prolong circulation time, and enhance tumour-specific targeting. In addition to serving as drug delivery vehicles, GNPs are widely explored for molecular imaging and photothermal therapy, where they convert light into heat to selectively destroy tumour cells. Their high atomic number also makes them potential radiosensitizers, enhancing the effectiveness of radiotherapy.

For example, multifunctional hybrid nanoparticles containing gold nanoparticles for imaging, quantum dots for near-infrared fluorescence imaging, PEG for prolonged circulation, tumour-specific F3 peptide for targeting, and doxorubicin as the therapeutic payload have demonstrated promising results in in vitro studies and mouse models of human breast cancer. However, these findings remain preclinical, and further clinical studies are required before their routine use in cancer therapy can be established.

2.3.2 Silver Nanoparticles (AgNPs) [24,25]

Silver nanoparticles (AgNPs) are biologically active nanoparticles that generally range in size from 1 to 100 nm. Their unique physicochemical properties have attracted considerable attention in biomedical research, particularly in cancer therapy. Unlike many other nanocarriers that primarily function as drug delivery systems, AgNPs also possess intrinsic anticancer activity, making them a promising therapeutic platform.

One of the major reasons AgNPs are widely investigated in cancer research is their ability to exhibit selective cytotoxic effects against various cancer cell lines while demonstrating comparatively lower toxicity toward normal cells under experimental conditions. However, most of these findings have been reported in preclinical studies, and further clinical investigations are required to establish their safety and therapeutic efficacy in humans.

The anticancer activity of AgNPs involves multiple mechanisms, including induction of apoptosis and autophagy, generation of reactive oxygen species (ROS), DNA damage, mitochondrial dysfunction, and cell-cycle arrest. AgNPs may also be employed as drug carriers to enhance targeted delivery of anticancer agents. Although passive accumulation through the Enhanced Permeability and Retention (EPR) effect may facilitate tumour localization, the intrinsic cytotoxic properties of AgNPs are considered one of their distinguishing characteristics. For example, 13 nm AgNPs have been reported to induce apoptosis in A549 human lung cancer cells under experimental conditions.

2.3.3 Iron oxide nanoparticles (IONPs) [26,27,28]

Magnetic nanoparticles (MNPs) are nanosized materials, typically ranging from 15 to 150 nm, that exhibit ferromagnetic, ferrimagnetic, or superparamagnetic properties. Their magnetic behaviour enables controlled delivery to target tissues using an external magnetic field, making them attractive nanocarriers for cancer diagnosis and therapy. Among magnetic nanoparticles, iron oxide nanoparticles (IONPs) are the most extensively studied and widely used in biomedical applications because of their excellent biocompatibility and magnetic properties.

The three most common forms of IONPs are magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), and hematite (α-Fe_2O_3). Among these, superparamagnetic iron oxide nanoparticles (SPIONs) have gained considerable attention because they can be used for targeted drug delivery, magnetic resonance imaging (MRI) as contrast agents, and magnetic hyperthermia for cancer treatment. In addition, recent preclinical studies have suggested that SPIONs may act as radiosensitizers, enhancing the response of tumour tissues to radiotherapy. However, further clinical studies are required to establish their safety and therapeutic efficacy in routine cancer treatment.

2.3.4 Quantum dots nanoparticles [29,30,31]

Quantum dots (QDs) are semiconductor nanoparticles that possess unique optical and electronic properties, including size-dependent fluorescence, high brightness, and excellent photostability. These characteristics make them valuable in cancer imaging, biosensing, and targeted drug delivery. Quantum dots can be conjugated with antibodies, peptides, or other targeting ligands to improve tumour-specific imaging and therapeutic delivery.

In addition to their diagnostic applications, QDs have also been investigated for photodynamic therapy (PDT) and theranostic applications, where diagnosis and treatment are combined in a single platform. However, many conventional quantum dots contain heavy metals such as cadmium, raising concerns regarding long-term toxicity and biocompatibility. Consequently, most applications remain preclinical, and further research is required before widespread clinical use.

2.3.5 Carbon dots [29,30,31]

Carbon dots (CDs) have emerged as promising carbon-based nanomaterials for cancer diagnosis and therapy because of their excellent biocompatibility, low toxicity, water solubility, and strong fluorescence properties. Their applications include drug delivery, bioimaging, photodynamic therapy (PDT), and theranostic approaches.

CDs can generate reactive oxygen species (ROS) upon light irradiation, making them useful photosensitizers for photodynamic therapy, which induces apoptosis in cancer cells. In addition, CDs are employed as fluorescent imaging agents for cancer detection and have shown potential in multimodal imaging techniques. They can also simultaneously deliver multiple therapeutic agents, making them suitable for combination therapy. For example, CDs may co-deliver a chemotherapeutic drug together with an immunomodulatory agent, thereby enhancing therapeutic efficacy while reducing the likelihood of drug resistance. Although these findings are promising, most evidence is derived from preclinical studies, and further clinical validation is required.

3. ADVANTAGES OF NANOPARTICLE-BASED DRUG DELIVERY. [32]

1. Drug loading is crucial for maintaining drug activity, as pharmaceuticals can be added to systems without inducing any chemical reactions due to their high drug loading.

2. The effectiveness of a medicine can be improved by regulating or sustaining the releasing of the substance.

3. Smaller capillaries can be penetrated by nanoparticles of small size, which permits medications to accumulate efficiently at specified regions.

4. Because liposomes and polymer nanoparticulate are typically biodegradable and never accumulate in the body, they may not pose a risk.

5. As the bioavailability of a medicine increases, its solubility also increases, allowing for more tailored drug administration.

4. DISADVANTAGES OF NANOPARTICLE-BASED DRUG DELIVERY. [32]

1. It is possible that the solvent system used in the preparation technique may have harmful effects.

2. Drug leakage and uncontrolled drug releases may be a significant issue.

3. The production expenses are significant, and the efficiency of encapsulation is low.

4. Manipulating nanoparticles in both their wet and dry states is a significant challenge.

5. LIMITATIONS [32]

Nanomaterial	Limitations
1.Silica based (mesoporous silica) nanomaterials.	1. Limited selectivity and adsorption capacity 2. Poor recovery 3. Weak thermal, chemical, and mechanical stability 4. Extensive cycling issues 5. Aggregation
2.Carbonaceous nanoparticles.	1. Hydrophobicity 2. Aggregation (poor suspension in aqueous media) 3. Low reactivity of carbon 4. High cost (e.g., carbon nanotubes) 5. Possible toxicity risks
3.Metal/oxide/quantum dot nanoparticles.	1. Low chemical stability and corrosion issues 2. High tendency to aggregate 3. Limited performance in complex biological systems 4. Low selectivity toward target molecules 5. Limited activity under visible light

6. CONCLUSION:

Nanoparticle delivery systems have proven themselves to be game-changers in oncology treatment. This method has several advantages over traditional chemotherapy – better targeting, lower toxicity and more efficient therapy. Both passive targeting (based on the EPR effect) and active targeting are promising methods which could be implemented in cancer treatment through the usage of either organic or inorganic nanoparticles. High cost of fabrication, poor encapsulation and stability are some of the drawbacks that need to be overcome before nanoparticle delivery systems become widely used in clinics.

Author Contributions: Mr. Gaurav Patil conceived the review, performed the literature search, analysed the published literature, and prepared the initial manuscript draft. Mr. Kartik Parmar contributed to literature collection, manuscript revision, and formatting. Drx. Kavita Rana supervised the work, critically reviewed the manuscript, and approved the final version.

Funding: The authors declare that no external funding was received for this work.

Conflict of Interest: The authors declare no conflict of interest.

Acknowledgements: The authors sincerely thank the Department of Pharmacy, Sigma University, for providing academic support and guidance during the preparation of this review article.

AI Use Statement: Artificial intelligence tools (ChatGPT, developed by OpenAI) were used only to improve language clarity, grammar, and manuscript organization. All scientific content, literature selection, interpretation, fact-checking, and final approval of the manuscript were performed by the authors, who take full responsibility for the accuracy and integrity of the work.

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