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A Review on: Nanotechnology in the Treatment of Cancer

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Abstract:
Cancer contributes major global health challenge, causing substantial mortality and negatively affecting patients' quality of life. Despite advances in cancer management, conventional treatments may damage healthy tissues, produce adverse effects and initiation ofdrugresistance. Thesechallengeshighlight a role related to improving early cancer detection and developing treatment approaches that gives active compound additional targetedtowards cancer cells. Nanomedicineshowssignificantfocus in this field because it offers opportunities to improve cancer diagnosis, drug delivery, and therapeutic performance. Various nanomaterials, including liposomes, dendrimers, polymeric micelles, and carbon tubular nanostructure, have beenanalyzed fortheirpotentialapplicationsincancermanagement.basedregardingtheirconstituentsas well as design, these systems may protect therapeutic agents from degradation, modify drug-release patterns, and improve drug accumulation at tumor sites.
Nanotechnology is also being explored as a strategy to address drug resistance through approaches such as inhibiting drug efflux, combining different therapeutic agents, modifying the tumor microenvironment, and delivering genetic materials that regulate resistance-associated genes.Thisreviewdiscussesthemajornanomaterialsinvestigatedincancerdiagnosisand treatment, their therapeutic applications, and their potential contributions to improving treatmentoutcomes.Italsohighlightsimportantchallengesrelatedtosafety,effectiveness, large-scale production, and clinical translation that must be addressedbefore the broader application of nanotechnology in cancer care.

Keywords: Nanotechnology, Nanomaterials, Nanoparticles, Cancer Diagnosis, Cancer Treatment, Targeted Drug Delivery, Organic Nanoparticles.

I. Introduction:

Cancer remains primary health challengeglobally and continues to place a considerable burden on healthcare systems. Although treatments such as surgery, chemotherapy,andradiotherapyhaveimprovedcancermanagement. In addition, certain tumor cells can formtolerancetowardsanticancer drugs, makingtreatment lesseffectiveand increasingthe risk of disease progression. suchdifficulties promoted scientists to explore improved diagnosticmethodsand treatment strategiesthat canact more selectively against cancer cells while limiting unwanted effects on normal tissues. Nanoscience gained significant preference in cancer research because it enables the development of materials and delivery systems including characteristicswhich varyinsuch larger-scale counterparts. Nanomaterials are commonly described as materials withdimensions measuring approximately1–100nanometers,althoughthedefinitionmayvarybased onthe field and application. In cancer care, nanotechnology is being investigated for diagnostic imaging,biomarkerdetection,andthedeliveryoftherapeuticagents.

Nanocarrierssuchas liposomes, polymeric nanoparticles, dendrimers, and polymeric micelles can be designed toprotectdrugsfromdegradation, influencetheirrelease,andaltertheirdistributionwithin the body. However, the extent towhichthese systems improve treatment depends ontheir composition,biologicalbehavior,alsofeaturesrelated to tumorthetumour. Anotherimportant area ofresearch utilized fornanotechnology toaddresscancerdrugresistance. Insensitivity might develop using multiple mechanisms, including increased removal of drugs from cancer cells,changesintherapeuticsites,improvedDNArecovery,reducedsensitivitytoprogrammedcell death, and changes in the tumour microenvironment. Nanotechnology-based approaches are being investigated to increase active compound

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depositionwithinneoplastic cells, deliver combinations of therapeutic agents, and transport genetic materials that influence resistance-related pathways. howeversuch approachesreported potential in experimental studies, their effectiveness varies according to the cancer type and the delivery system used. Therefore, another investigationnecessary to establish their safety and therapeuticvalueinclinicalpractice.

Beyonddrugdelivery,nanotechnologyisbeing explored for early cancer detection, improved diagnostic imaging, and the improvement of theranostic systems, which integrate diagnostic and therapeutic functions within a single platform. Nevertheless, challenges involving toxicity, biocompatibility, biodegradation, manufacturing consistency, cost, and clinical translation continue to limit the wider use of some nanotechnology-based approaches. This review examines the major nanomaterials investigated in cancer diagnosis and treatment, their mechanisms of action, and their potential role in addressing drug resistance. It also discusses the current limitations and future research directions required to support their safe and effective clinical application [1,2].

Cancer: An Overview

Cancer comprises a group of diseases in which abnormal cells multiply beyond normal growthcontrol.suchcellscanenter nearbytissuesandspreadtootherbody parts through the blood or lymphatic system. This spread is termed metastasis is a major feature of malignant cancer.

The development of cancer involves changes in DNA sequence which modulate cell multiplication, survival, and normalcellularfunctions. therefore, cancercellsmay continuegrowingwhennormal cellswouldstopdividingorundergoprogrammedcelldeath.suchoutcomesmayoriginatethrough inherited genetic alterations, mistakearisingthroughout cellularproliferation, or exposure to certain cancer-causing agents [3].

Cancer can originate in almost any tissue or organ. Some types form solid tumour, while others, such as leukemia, mainly affect blood-forming tissues. Causes relatedto malignanttransformation include increasing age, tobacco use, certain infections, radiation exposure,andinheritedsusceptibility.Thecontributionofthesefactorsvariesaccordingto the type of cancer [4].

Different cancers vary in their origin, biological behavior, progression, and response to treatment. Identifying these differences helps healthcare professionals select appropriatetreatmentstrategies and supports research intomore precise diagnostic and therapeutic approaches [5].

Categories of Cancer:

Cancers are classified according to tissue from which they develop.

The major categories include

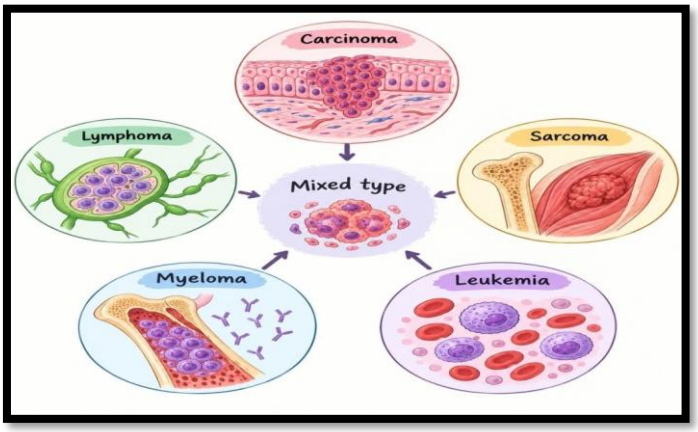


Figure1:categoriesofcancer[6]

1. **Carcinoma:**Thistypeoriginatesinepithelialcells, whichcoverbody surfacesand line internal organs. Examples include adenocarcinoma and squamous cell carcinoma.
2. **Sarcoma:**Sarcomasarisefromconnectiveandsupportivetissues,includingbone, muscle, fat, and cartilage. Osteosarcoma and liposarcoma are examples.
3. **Lymphoma:** Lymphoma develops from

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lymphocytes, which are immune-system cells.

4. **Leukemia:** Leukemia affects blood-forming tissues, particularly the bone marrow, and leads to transformation within abnormal blood cells.
5. **Myeloma:** Myeloma is type of cancer that starts inantibody-producing cells. several myeloma influence plasma cells in the bone marrow and may cause bone damage.

Nanotechnologyin Cancer Diagnosis:

Earlyandaccuratecancerdiagnosisplays a crucial role inisolatingsuitablemedical careand improving patient outcomes. Nanotechnology is being investigated to overcome some limitations of conventional diagnostic methods by improving biomarker detection, identifying cancer-associated cells, and enhancing medical imaging [7].

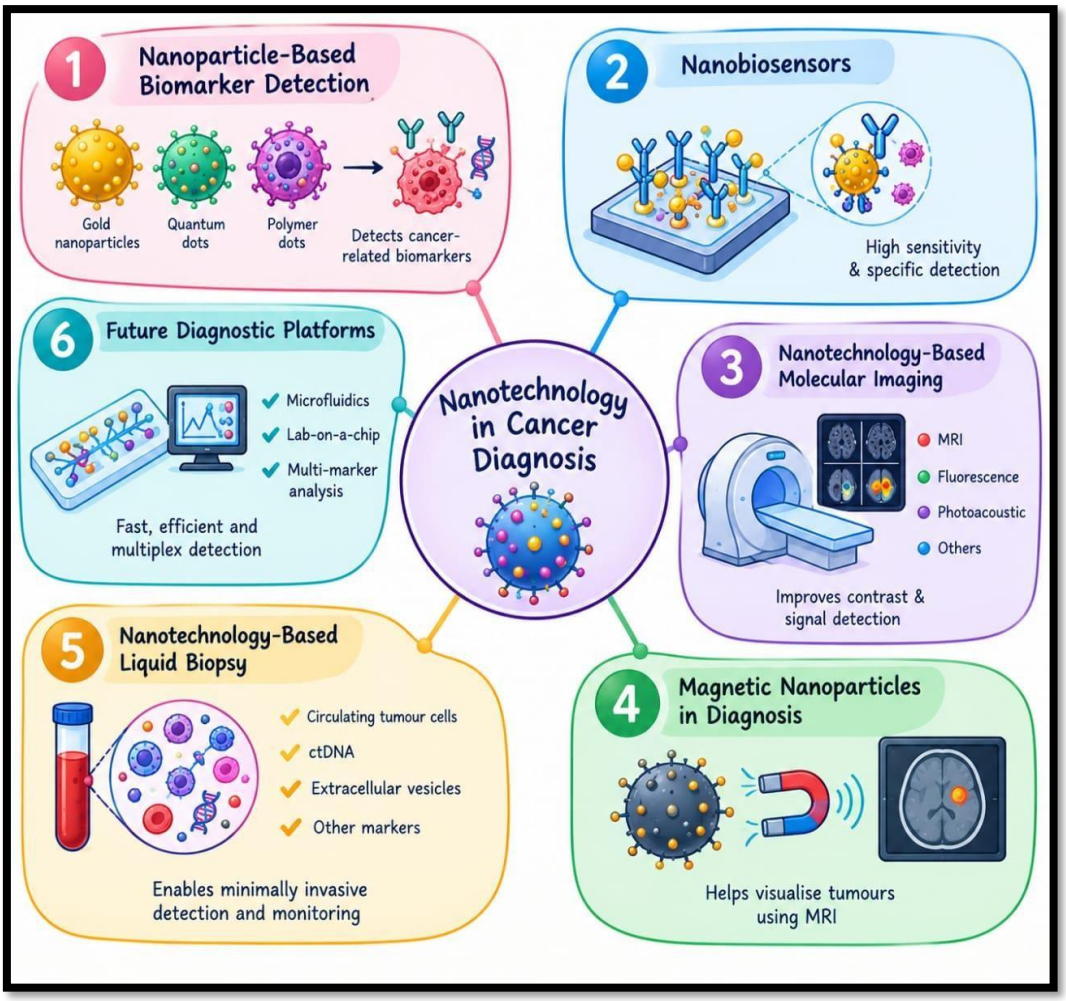


Figure 2:nanotechnologyincancerdiagnosis

1. **Nanoparticle-Based Biomarker Detection**

Nanoparticles have distinctive optical, magnetic, and electrically poweredaspectswhich create these useful for detectingcancer-associatedbiomarkers. Goldnanoparticles, quantum dots,andpolymerdotsarebeingstudiedforidentifyingproteins,nucleicacids,and other biological molecules that may indicate the presence of cancer [7].

2. **Nano biosensors**

Nano biosensorscombinenanomaterialswithbiological recognitioncomponentstodetect specific cancer biomarkers. substancesconsisting gold and nanoscale silver particles, graphene, carbon-based nanotubes, and magnetic nanoparticles have been

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investigated to identifying biological indicatorslinked to breast, lung, prostate, and colorectal cancers [8].

3. **Nanotechnology-Based Molecular Imaging**
   Nanoparticles are being developed as imaging agents to improve contrast and signal detection during cancer imaging. Depending on their composition, they may support MRI technology, fluorescence-based detection, photoacoustic imaging, or other molecular imaging techniques. However, many nanoparticle-based imaging systems remain at the preclinical or early clinical research stage [9].
4. **Magnetic Nanoparticlesin Cancer Diagnosis**
   SPIONswereevaluateddue to their capacity to alter magnetic resonance technology. Their magnetic properties may help researchers visualize biological tissues and investigate tumour-related changes. Their diagnostic usefulness depends on formulation, biodistribution, safety, and the specific imaging application [10].
5. **Nanotechnology-Based Liquid Biopsy**
   Liquid biopsy involves analyzing cancer-associated material present in blood or other body fluids. Such approaches may support minimally invasive cancer detection and disease monitoring, although their clinicalaccuracy requires validation for each intended application [11].
6. **Future Diagnostic Platforms**
   Emerging diagnostic platforms combine nanomaterials with microfluidic devices, lab-on-a-chipsystems,andadvancedbiomarkeranalysis. Theseapproachesaimtoprocess smallsamplesand detect multiplecancer-associated markersefficiently. Further work isneeded toestablishtheirreproducibility, safety, affordability, andusefulnessinroutine clinical practice [12].

Types of Nanoparticles Used in Cancer Therapy:
Nanoparticles used in cancer treatment can be classified into three main groups: organic, inorganic, and hybrid nanoparticles. Each group has different structural and physicochemicalpropertiesthat influencedrug loading, drugrelease, tumourdelivery, and therapeutic activity.

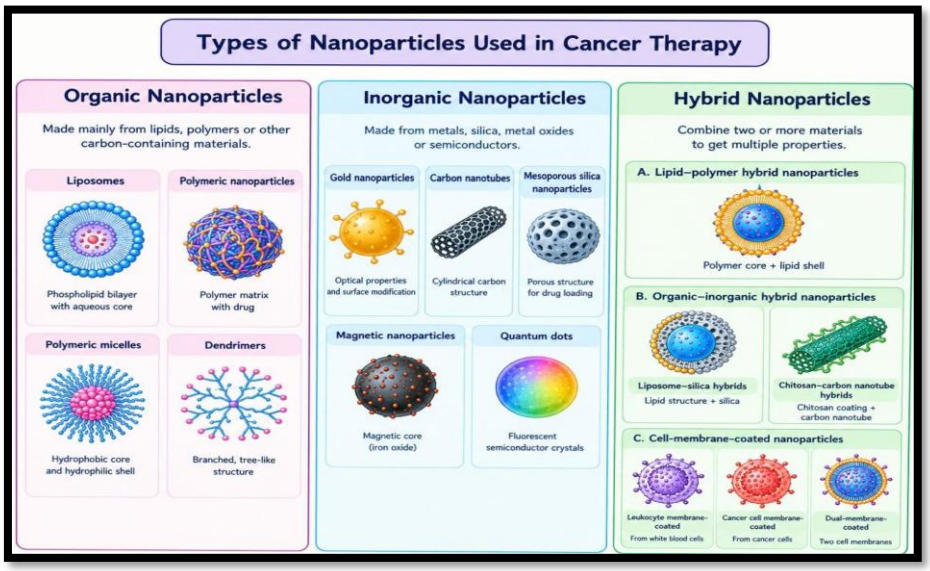


Figure3:categories of Nanoparticles used in cancer therapy[13].

1. Organic Nanoparticles: Organic nanoparticles are prepared mainly from lipids, polymers, or other carbon-containing biological or synthetic materials. Their composition can be adjusted to improve drug solubility, protect therapeutic agents, and regulate drug release.

1.1 Lipid-based nanoparticles

Lipid based nanocarrieris tiny, lipid bilayer vesicles surrounding an aqueous compartment. Water-soluble medicinal productsmay be enclosed inside the aqueouscore, whilelipid-solublemedicinal

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products maybe entrapped inlipidbilayer. Thisallows liposomes to carry different types of therapeutic agents. Some liposomal anticancer medicinesareclinicallyapprovedandcanalterdrugdistribution andtoxicitycomparedwith conventionalformulations.However,theireffectiveness dependsonthedrug,formulation, and cancer being treated.

1.2 Polymer-basednanoparticles

Polymer based nanoparticles composedof natural or synthetic polymers, including biodegradable materials such as poly (lactic-co-glycolic acid). Anticancer drugs are introducedintopolymermatrix orattached toitssurface. Their performance depends on polymer composition, particle size, drug-loading capacity, and degradation behavior.

1.3 Polymericmicelles

Polymericmicellesarenanoscalestructuresformedwhenamphiphilicpolymersassemble inaliquidenvironment.Theytypicallyhaveahydrophobiccoreandahydrophilicouterlayer. The core can accommodate poorly water-soluble anticancer drugs, while the outer layer helpstheformulationdisperseinaqueousfluids.Polymericmicellesmayimprovetheapparent solubilityanddeliveryofcertaindrugs,althoughstability afteradministrationand drug-release behavior remain important considerations.

1.4 Dendrimers

Dendrimers are highly branched, tree-like macromolecules with a central core and several layers of branches. Their numerous surface functional groups provide sites for attaching drugs, targeting ligands, or imaging molecules. They are being investigated for controlled drug delivery and the simultaneous delivery of multiple therapeutic agents. Their clinical application requires careful assessment of toxicity, biodegradability, and elimination from the body [14].

2. Inorganic Nanoparticles:

Inorganic nanoparticles are made from materials such as metals, silica, metal oxides, or semiconductors. Their distinctive optical, magnetic, and structural characteristics make them usefulfor investigating drug delivery, imaging-guided therapy, and physicalmethods of tumour destruction.

2.1 Goldnanoparticles

Gold nanoparticles have useful optical properties and a surface that can be modified with drugs or targeting molecules. Researchers are investigating them for antineoplastic agent delivery also for photothermal therapy. In photothermal therapy, the particles absorb suitable light and convert its energy into heat, which can damage cancer cells.

2.2 Carbonnanotubes

Carbonnanotubesarecylindricalstructurescomposedofcarbonatomsarrangedinatube-likeform. Theirhighsurfaceareaandability tointeractwithdifferent moleculesmakethem candidatesforcarryinganticancerdrugs,proteins,andgeneticmaterial.Theyarealsobeingstudied for photothermal applications. However, aggregation, persistence in biological tissues, and possible toxicity need to be addressed before wider clinical use.

2.3 Silica based nanoparticles

silica based nanoparticles contain numerous pores that can hold therapeutic molecules.Theirporesize,surfacechemistry,andcoating canbemodifiedtoinfluencedrug loadingandrelease.Thesefeaturesmakethempromising carriersforanticancerdrugsand for systems designed to release drugs under particular conditions, such as changes in pH. Their safety depends on particle characteristics, surface modification, dosage, and elimination from the body.

2.4 Magneticnanoparticles

Magnetic nanoparticles are commonly prepared from iron oxide and can be coated with materials that improve their stability in biological fluids. They are being investigated for magnetic hyperthermia, drug delivery, and imaging-guided treatment. During magnetic hyperthermia, an alternating magnetic field causes suitable particles to generate heat that maydamagetumourcells.Althoughthisapproachispromising,controllingheating,particle distribution, and potential effects on healthy tissues remains important.

2.5 Quantumdots

Quantum dots are semiconductor nanocrystals that emit light when excited by an appropriate energy source. Their optical properties make them useful for fluorescence imaging, tracking biological processes, and developing multifunctional diagnostic and therapeutic systems. Some quantum dots contain elements that may be toxic, so their composition, surface coating, degradation, and long-term retention must be evaluated carefully. Their role in cancer

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therapy remains largely investigational [15].

3. Hybrid Nanoparticles: Hybrid nanoparticles combine two or more different materials to bring together useful propertieswithinasingledeliverysystem.

3.1 Lipid–polymerhybridnanoparticles

Lipid–polymer hybrid nanoparticles commonly consist of a polymer-based core with a surrounding lipid layer. The polymer core can provide structural stability and drug-loading capacity, while the lipid coating may improve interactions with biological environments. Their design can be adjusted to control drug release and modify particle behavior after administration.

3.2 Organic–inorganichybridnanoparticles

Organic–inorganic hybrids combine organic materials, such as lipids or polymers, with inorganic materials, such as silica, gold, or magnetic nanoparticles. This combination can unite drug-carrying capacity with useful physical properties.

3.3 Liposome–silica hybrids:

These systems combine a lipid-based structure with a silica component. The porous silica may provide additional space for loading therapeutic molecules, while the lipid layer can act as a protective coating and influence drug release.

3.4 Chitosan–carbon nanotube hybrids:

Chitosan is a natural polymer obtained from chitin, whilecarbonnanotubesarecarbon-basednanostructures.

3.5 Cell-membrane-coatednanoparticles

Cell-membrane-coated nanoparticles consist of a nanoparticle core covered with membranematerialobtainedfrombiologicalcells. Thecoatingmay helpmodify interactions withtheimmunesystemandinfluencehow theparticlesinteract withtumourtissue.Three types are illustrated in your figure.

3.6 Leukocyte membrane-coated nanoparticles: These nanoparticles use membranes obtainedfromwhitebloodcells.Themembranecomponentsmayhelptheparticlesinteract with inflammatory environments or evade certain immune-clearance processes.

3.7 Cancer-cell membrane-coated nanoparticles: These particles are coated with membranes obtained from cancer cells. The coating may retain some surface molecules associatedwiththeoriginalcells,potentiallysupportingrecognitionofsimilarcancercells.

3.8 Dual-membrane-coated nanoparticles: These nanoparticles combine membrane components from two different cell types. The purpose is to integrate selected biological functions, such as immune interaction and tumour recognition, within one system. Their manufactureismorecomplex,andconsistentmembranecomposition,stability,andsafety are important challenges [16].

MechanismofActionofDifferentNanoparticlesin Cancer Therapy:

Themechanism ofactionvariesaccording tothecomposition, structure, surfaceproperties, and therapeutic function of each nanoparticle. Some nanoparticles carry anticancer drugs into cancer cells, whereas others produce heat, support targeted delivery, or assist in combined treatment.

1. Organic Nanoparticles:

1.1 Liposomes

Liposomes act as carriers by enclosing anticancer drugs within their aqueous core or phospholipid bilayer. After administration, they circulate through the body and may reach tumour tissues. Depending on their composition and surface properties, theseliberatethe active compound outside or inside cancer cells. The released drug then acts on its cellular target, for example, by interfering with DNA replication or cell division. Liposomal encapsulation can alter drug distribution and reduce exposure of some healthy tissues, although this benefit depends on the particular formulation and drug.

1.2 Polymericnanoparticles

Polymeric nanoparticles carry anticancer agents within a polymer matrix or attachthem to theparticlesurface.Afterreachingthetumourregion,thedrugisreleasedthroughdiffusion, polymer degradation, or a combination oftheseprocesses. Some formulationsaredesigned to respond to conditions such as acidic pH or with particular enzymes. The released drug then enter cancerous cell and interactthroughmethodsrequiredto their growth and survival. The release rate depends on polymer composition, particle structure, and drug properties.

1.3 Polymericmicelles

Polymeric micelles form when amphiphilic polymers assemble into structures with a hydrophobic core and a hydrophilic outer layer. Poorly water-soluble anticancer drugs canbe carried

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within the core, helping them disperse in aqueous biological fluids. Following administration,themicellesmaytransport thedrugtowardstumourtissue.Drugreleasecan occur through diffusion, micelle disassembly, or changes in the surrounding environment. The released drugthen acts on cancer cells, although micelle stability and premature drug leakage can influence treatment effectiveness.

1.4.Dendrimers

Dendrimers possess highly branched structures withnumerous surface functionalgroups. These groups can be used to attach anticancer drugs or targeting ligands, while certain dendrimers can also hold drugs through internal interactions. After reaching cancer cells, thedrugmaybereleasedbybondcleavage,changesinpH, orotherformulation-dependent processes. Targeting ligands may improve binding to selected cellular receptors, and internalization can facilitate delivery of the therapeutic agent. Their biological activity and safety depend on dendrimer size, surface charge, composition, and biodegradability.

2. Inorganic Nanoparticles

2.1 Goldnanoparticles

Gold nanoparticles interact with light through their surface Plasmon resonance, a phenomenon in which electrons on the particle surface oscillate in response to incident light. In photothermal treatment, light energy is converted into heat that can destroy tumour cells. The effectiveness governed by particle shape, size, surface modification, light exposure. [17]

2.2 Carbonnanotubes

These areactascarriersforanticancerdrugsandothertherapeuticmolecules because of their surface extent and modifiable surfaces. Drugs may beattached to thenanotubes through chemical bonds or non-covalent interactions. After the carrier reaches the target region, the therapeutic agent may be released and interfere with cancer cell growth.Certaincarbonnanotubescanalsoabsorbnear-infraredlightandgenerateheatfor photothermal treatment.[18]

2.3 Porous silica nanocarriers

MSNs contain many small pores that act as reservoirs for anticancer drugs. The drug is loaded into these pores and may be retained using surface coatings or molecular gates. After the particles reach the intended site, API deliver through diffusion, degradation of the coating, or a response to stimuli such as acidic pH or enzymes.This mechanism allows researchers to investigate controlled drug release, although particle degradation, clearance, and toxicity must be evaluated [19].

2.4 Magneticnanoparticles

Iron oxidenanoparticles,respondtoexternalmagnetic fields may modified to carry therapeutic agents. In magnetic hyperthermia, an alternating magnetic field causes suitable particles to generate heat, that damage malignant cells when an effective temperature is achieved.Some magnetic nanoparticles can additionally support magnetic resonance imaging. Their therapeutic performance depends on magnetic properties, tumour accumulation, field conditions, and control of heat distribution [20].

2.5 Quantumdots:

Incancerresearch,quantum dotsaremainlyusedtolabelbiologicalmolecules,visualize cancer-associatedtargets,andtrackcellularprocesses.Whenlinkedtoantibodiesor othertargetingmolecules,theycanbindtoselectedbiologicalmarkersandproduceadetectable fluorescentsignal.Someexperimentalsystemscombine quantumdotswithdrugcarriersor light-responsive components to support treatment as well as imaging[21].

III. Hybrid Nanoparticles:

3.1 Lipid–polymerhybridnanoparticles

Lipid–polymerhybridnanoparticlesgenerallycontainapolymericcoresurroundedbyalipid layer. Thecorecanretaintheanticancer drugand influenceitsrelease, whilethelipid layer canhelpstabilizetheformulationinbiologicalfluids.Afteradministration,theparticlesmay transport the drug towards tumour tissue, where the therapeutic agent is released through diffusion, polymer degradation, or other formulation-dependent processes. By combining featuresregarding lipids and polymers, these systems aim to improve drug stability and delivery while controlling unwanted drug release [22].

3.2 Liposome–silicahybridnanoparticles

Liposome–silica hybrid nanoparticles combine lipid-based structures with silica components. Depending on their design, drugs may be carried within the liposomal compartment, the silica pores, or both. The silica component can

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provide additional drug-loading capacity, while the lipid component may help regulate interactions with the surrounding biological environment. After reaching the target region, the formulation releases its therapeutic cargo through membrane transport, diffusion, modifications in carrier structure.

3.3 Chitosan–carbonnanotubehybridnanoparticles:

Chitosan–carbon nanotube hybrids combine the drug-carrying and surface-modification properties of chitosan with the large surface area of carbon nanotubes. Anticancer agents maybeattachedtoorincorporatedintothehybridstructure .Afterthenanostructurereact with tumourcells, bioactive compoundis deliveredandactonintracellulartargets.Chitosanmayimprove the dispersion or functionalization of carbon nanotubes in certain formulations, can create more binding sites for attachment of drug.

Cell-Membrane-CoatedNanoparticles

3.4 Leukocytemembrane-coatednanoparticles

Leukocytemembrane-coatednanoparticlesusemembranesobtained throughleukocytes tocoverananoparticlecorecontainingatherapeuticagent .Membrane-associatedproteins may help the particles interact with inflammatory signals and may reduce recognition by someimmune-clearancemechanisms.Afterreachingtumourtissue,the nanoparticlecoreliberates active agent and produce an anticancer effect. The membrane coating influences the particle's biological interactions, but it does not guarantee tumour-specific delivery or complete avoidance of immune clearance.

3.5 Cancer-cellmembrane-coatednanoparticles

Cancer-cell membrane-coated nanoparticles use membranes obtained from cancer cells as a biological coating around a nanoparticle core. Some surface proteins retained in the membrane may support recognition of related cancer cells, a property often described as homotypic recognition. This may improve interactions with selected tumour cells and help deliveranencloseddrug.Cancer-cellmembranesarealsobeinginvestigatedinvaccine-like systemsbecausetheycanpresenttumour-associatedantigenstotheimmunesystem.The effectiveness depends on the source of the membrane, the tumour type, and the formulation, while safety and manufacturing consistency remain important concerns.

3.6 Dual-membrane-coatednanoparticles

Dual-membrane-coatednanoparticles are surroundedby two biological or functional membrane layers aroundatherapeuticcore. Theaimisto integratecomplementary biologicalfunctions, such as interactions with the immune system and recognition of tumour cells. Following administration, the combined membrane coating may influence circulation, immune interactions, and tumour association, while the core carries or releases the therapeutic agent. [23].

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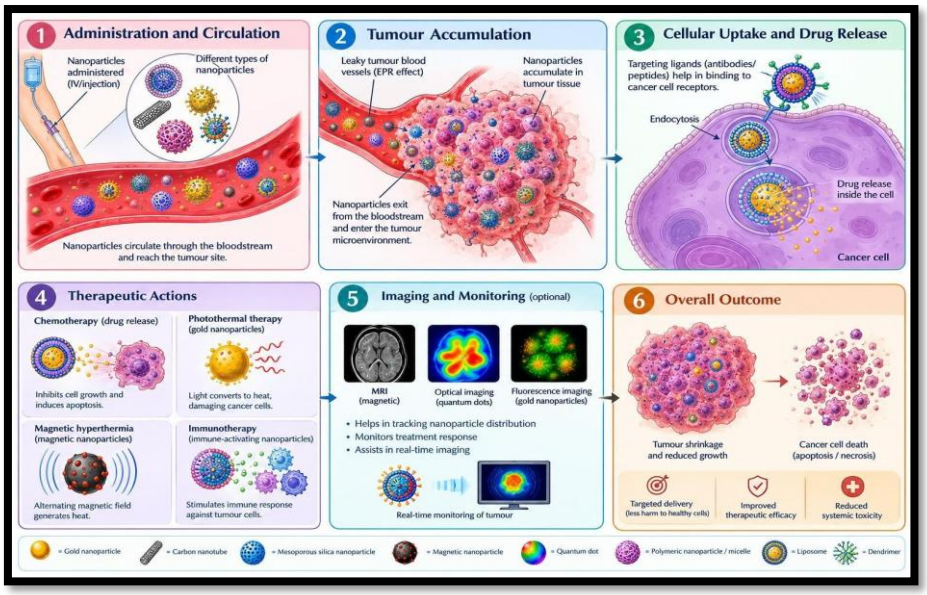


Figure 4: GeneralmechanismofNanoparticleincancertherapy[24].

Strategies of Nanotechnology in Cancer Treatment:

Nanotechnology has become an important area of cancer research because it modifiesexisting treatments and developing alternative therapeutic approaches. Its applications extend beyond drug delivery and include strategies to overcome drug resistance, improve immune responses, reduce treatment-related side effects, and address differences in tumour characteristics. Researchers are also exploring nanotechnology-based systems that combine multiple therapeutic functions to achieve better tumour control[25].

Minimizing Multidrug Resistance

Resistance to multiple drugsisoneofthemajorobstaclestosuccessfulcancertreatment.Itarises whenneoplasticcellsresult inlessresponsivetowardsanticancerdrugs,allowingsomecellstosurvive despite treatment. Nanotechnology is being investigated as a means of addressing this problem by combining different therapeutic agents and targeting biological mechanisms involvedindrugresistance.Such as,investigators evaluatingnanoparticlesthatcarry both anticancer drugs and genetic materials designed to interfere with resistance-related pathways.

ImprovingCancerImmunotherapy

Such approaches may improve the response of resistant cancer cells; however,their effectiveness depends on the underlying resistance mechanism and the type of tumour being treated [26].

ImprovingCancerImmunotherapy

Cancer immunotherapy aims to strengthen the body's immune system so that it can recognizeanddestroymalignantcells.However,somet umourevadesimmunedetectionor creates an environment that weakens immune activity. Nanotechnology canexaminesuchdrawbacksthroughimprovement about nanoparticle-basedcancervaccines,immune-stimulating formulations, and systems designed to deliver immunotherapeutic agents to specific sites. Such techniquescurrently monitored to improve antigen delivery, stimulateantitumorimmuneresponses, and supportexistingimmunotherapies. additionalstudyrequired to determine which formulations provide the greatest benefit while maintaining an acceptable safety profile [27].

CombiningDifferentCancerTreatments

Asingletreatment maynot besufficient tocontrolcancerbecausetumourcellscanrespond differently to individual therapeutic approaches. Combining treatments whichrespondbyvariousmode of action is therefore an important area of cancer research. Nanotechnology mightimprove progressrelated to combination therapies involving chemotherapy, immunotherapy, photothermal therapy, and photodynamic therapy. Some nanoparticle systemsaredesignedtodelivermultipletherapeuticage

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ntstogether,whileotherscombine drug delivery with heat- or light-based treatment. These approaches may improve tumour control and reduce the likelihood of treatment failure, although their safety and effectiveness must be established for each specific combination [28].

SupportingPersonalizedCancerTreatment

Tumors differ in their genetic composition, molecular characteristics, and response to treatment.Consequently,atherapywho actefficiently to singlepatientmaybelesseffectivefor another. Nanotechnology may contribute to personalized cancer care through the development of diagnostic and therapeutic systems that respond to particular tumour characteristics[29].

ReducingTreatment-RelatedToxicity

Conventional anti-tumour therapies can damage normal tissues as well as cancer cells, resulting in unwanted complications may affect patient's daily lives and ability to continue treatment. Nanotechnology offers a possible way to improve the distribution of anticancer agents and increase their accumulation at the intended treatment site. Some nanomedicinesaredesignedtomodify drugreleaseoralterthecirculationanddistribution of therapeutic agents within the body. These features may reduce exposure of certain healthytissuestoanticancerdrugs[30].

Addressing Neoplasm variability

Tumour variabilityindicates differences in the biological aspects of abnormal proliferating cells within the same tumour or between separate tumour sites. These variations can influence how cancer progresses and how effectively it responds to treatment. Nanotechnology-based approaches are being studied to address this challenge through multifunctional formulations and combinations of drug which focus on various cancer-related pathways. Suchstrategiesmay help researchersinvestigatediversetumour cellpopulations and develop treatments that act against more than one biological target [31].

PreventingCancerRecurrenceandMetastasis

Cancer recurrence occurs when the disease returns after treatment, whereas metastasis involvesthespread ofcancercellsfrom theoriginaltumourtootherpartsofthebody.Both processes can make cancer treatment more difficult. These developments may eventually contribute tobetter long-term disease control; however, the preventionofrecurrenceandmetastasishasnotbeenestablishedfor nanotechnologyasa whole and requires further experimental and clinical evidence [32].

DevelopingMultifunctionalNanomedicines

Multifunctional nanomedicines are being developed to combine two or more useful functionswithinasinglenanoscalesystem.Dependingo ntheirdesign,theseplatformsmay deliver anticancer agents while also enabling tumour imaging or the assessment of treatmentresponses.Forexample,asystemcombiningdrugdeliveryandimagingmayhelp researchersobserve thedistributionofa therapeutic agent and study itseffects on tumour tissue. However, the complexity of these systems, together with the need to establish their safety, stability, andmanufacturingconsistency, remainsanimportant consideration forfutureclinicaluse [33].

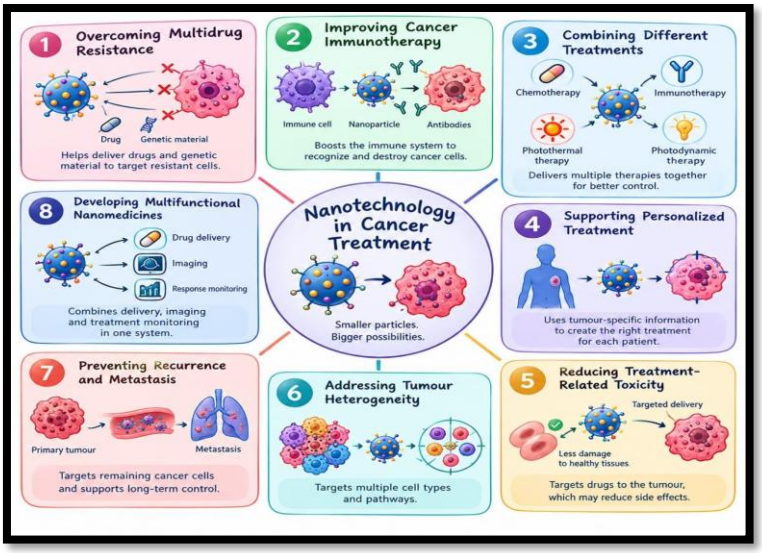


Figure 5:strategiesofnanotechnologyincancertreatment

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Applications of Nanotechnology in the Treatment of Cancer:

Nanotechnology has created new opportunities in cancer treatment by improving drug delivery, supporting targeted therapy, and introducing alternative methods for destroying cancer cells.

1. **PhotodynamicTherapy**
   In photodynamic therapy, nanoparticles can help transport photosensitizing agents to tumour tissues. these agents generate reactive oxygen species that damage cancer cells. Nanocarriers may also improve photosensitizerstabilityandcellularuptake,potentiallyincreasing efficiencyrelated to this treatment.
2. **TargetedDrugDelivery**
   Nanoparticles can be modified with specific targeting molecules that help them recognize cancer-associatedmarkers.Thisapproachmayimprovedrugdeliverytotumourtissuesand reduce unnecessary exposure of healthy cells to anticancer agents. However, successful targeting depends on the availability of suitable tumour markers and the ability of nanoparticles to reach cancer cells within the tumour environment.
3. **Improved Chemotherapy**
   Nanocarriers,includingliposomesandpolymeric nanoparticles,canimprovethesolubility and stability ofcertainanticancerdrugsand help controltheirrelease. Somenanoparticle-basedformulationsarealreadyusedclinicallytotreatspecificcancersTheseformulations may also alter drug distribution in the body, potentially improving therapeutic outcomes in selected patients.
4. **GeneTherapy**
   Nanoparticles can carry genetic materials, such as small interfering RNA (siRNA) and messenger RNA (mRNA), into target cells. These materials may regulate cancer-related genes and interfere with biological processes involved in tumour growth.Effective gene delivery requires protection of the genetic material from degradation and successful entry into target cells.
5. **Nanotheranostics**
   Nanotheranostics combines diagnostic imaging and treatment within a single platform.
   Thesesystemsmayhelplocatetumour,delivertherapeuticagents,andmonitortreatment responses, potentially supporting more personalized cancer care. Integrating imaging and therapy may also help researchers study nanoparticle distribution and evaluate treatment responses during preclinical investigations [34].
6. **RadiationTherapyEnhancement**
   Certain nanomaterials may increase the effects of radiation on cancer cells by enhancing energy deposition or influencing cellular responses. This strategy is being investigated to improve tumour control while limiting damage to surrounding healthy tissues. Some high-atomic-number nanomaterials, such as gold nanoparticles, are being studied as radiosensitizers to enhance radiation-induced damage in tumour cells.
7. **PhotothermalTherapy**
   Certainnanoparticles,includinggold-basednanomaterials,absorblightandconvertitinto heat.Thisheatcandamagecancercells,andresearchersareinvestigatingcombinationsof photothermal therapy with chemotherapy and immunotherapy. The effectiveness of photothermaltherapydependsonlightpenetration,heatdistribution,andfeatures of nanoparticles used [35].
8. **MagneticHyperthermia**
   Magnetic iron oxide particles, can produce heat when exposedtoanalternatingmagneticfield.Thegeneratedheatmaydamagecancercellsand couldbecombinedwithchemotherapyorradiationtherapytoimprovetreatment outcomes. This approach offers the possibility of localized heating, although temperature control and nanoparticle distribution remain important challenges [36].
9. **CombinationTherapy**
   Nanoparticlescancarrytwoormoretherapeuticagents, allowingtreatmentswithdifferent mechanismsofactiontobecombined.Thisapproachmayimprovetumourcontrolandhelp addressdrugresistance,althoughtheeffectivenessdependsonthetreatmentcombination and cancer type. Co-delivery may help coordinate the release of different agents, but the appropriate drug ratio and release profile must be carefully optimized.
10. **CancerImmunotherapy**
    Nanoparticles can deliver tumour antigens, immune-stimulating agents, and other

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immunotherapeutic molecules to support the immune system's ability to recognize and attack cancer cells. Nanoparticle-based vaccines and immune-modulating systems are being investigated to strengthen antitumor immune responses and improve the effectiveness of existing immunotherapies [37,38].

Limitations and Challenges of Nanotechnology in Cancer Treatment:

Although nanotechnology has shown promising potential in cancer treatment, certain challenges need to be addressed to improve its clinical application. The major challenges include the following:

1. **ManufacturingChallenges:**
   Producingnanoparticlesona largescalewhilemaintainingconsistent size, stability, drug-loading capacity, and quality can be technically challenging and expensive.
2. **BiologicalBarriers:**
   After administration, nanocarrierscan influenceviaplasma proteins and other biomolecules, that could influence their circulation time, distribution, and ability to reach the tumor site
   Some nanomaterials may cause unwanted biological effects or accumulate in certain organs. Therefore, appropriate safety assessments are necessary to establish their suitability for long-term use
3. **DrugReleaseControl:**
   Achieving the desired drug-release rate at the tumor site remains challenging. Premature drugreleasecantriggerundesirableadverse reactions,whereasinsufficientreleasemayred ucethe therapeutic effect [39].
4. **Patient-to-PatientVariability:**
   Differencesinbloodcirculation,tumorcharact eristics,andindividualbiologicalresponses mayinfluence how nanoparticlesbehave in thebody.Consequently,the effectiveness ofthe same nanoparticle formulation may vary among patients [40].
5. **TargetingandPenetration:**
   Differences in tumor characteristics and the complex tumor microenvironment may limit theuniformdistributionofnanoparticles.This canaffectdrugdeliveryandreducetreatment effectiveness[41].
6. **ClinicalTranslation:**
   Although many nanoparticle-based techniqueillustratedbeneficialevidencesduri ng preclinical studies, further clinical research and standardized regulatory assessments are required to establish their safety and effectiveness in humans.

Future Perspectives of Nanotechnology in Cancer Treatment

Nanotechnologyhassubstantialcapacityinpr omotingcancerdiagnosisandtreatment in the coming years. Further investigationsare expected to prioritize in developing safer and more effective nanomedicineswhichtransfermedicinal substancetotumour tissueswithgreater precision, improve drug release, and reduce unnecessary exposure of healthy cells. Advances in nanoparticle designmay support the development of multifunctionalsystems that combine drug delivery, diagnostic imaging, and treatment monitoring within a single platform. Researchers are also investigating nanotechnology-based approaches for overcoming drug resistance, delivering genetic materials, strengthening antitumor immune responses, and combining different treatment methods to address the complex nature of cancer.

Another important direction is the integration of nanomedicine with personalized cancer treatment. By combining tumour-specific biomarkers, genetic information, and diagnosticimaging,researchersmaybeabletodeveloptr eatment systemsbettersuitedto the biological characteristics of individual patients. However, the successful clinical application of these technologies will depend on overcoming several challenges, including nanoparticle toxicity, inconsistent delivery to tumour, long-term safety, manufacturing costs, and regulatory

Conclusion

Different types of nanoparticles, including organic, inorganic, and hybrid nanomaterials, are analyzed to fields of area involving chemotherapy enhancement, radiation therapy, magnetic hyperthermia, light-induced cancer treatment, photothermal treatment, gene- based treatment and cancer immunotherapy.

These approaches may improve drug delivery, support combination treatments, and help address challenges such as multidrug resistance and tumour heterogeneity. Despite these advances, concerns regarding toxicity, biodistribution, long-

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term safety, manufacturing complexity, and treatment costs remain important.

Further research and well-designed clinical trials are necessary to establish their safety and therapeutic benefits.

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