INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

Review Article

Targeted Drug Delivery System Using Nano Technology

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ARTICLE INFO

Published: 16 Jul. 2025
Keywords:
Nanotechnology, Bioavailability enhancement, Liposome, Polymeric nanoparticles, Enhanced permeability and retention (EPR).
DOI:
10.5281/zenodo.15974987

ABSTRACT

The drug delivery industry underwent major progress after nanotechnology emerged to develop original solutions for directed medicine release strategies. Nanocarriers employed in targeted drug delivery system (TDDS) serve to increase drug therapeutic effects while decreasing adverse effects and optimizing pharmacokinetic drug characteristics by transporting drugs directly to targeted diseased tissues and cells. Various nanomaterials including liposomes and dendrimers and polymeric nanoparticles and micelles and solid lipid nanoparticles function as drug delivery systems because they provide distinctive benefits regarding size specifications along with drug-loading potential and surface modification capacities. Active or passive targeting forms the basis of these systems through which ligands including antibodies, peptides, or aptamers recognize target cell receptors or the system benefits from tumour-enhanced permeability and retention (EPR) effects. The application of nanotechnology-based delivery systems demonstrates promising results for treating oncologic conditions and neurological afflictions and infectious disorders because researchers already deployed various formulations into clinical applications. Different barriers including toxicity and scalability problems and regulatory difficulties still stand in the way of progress. The paper examines contemporary developments in nanotechnology while addressing different nanocarrier methods and targeting mechanisms and future directions for nanotechnology drug delivery systems which show potential to revolutionize current pharmaceutical treatment approaches.

INTRODUCTION

Fast growth in nanotechnology research occurs in modern times due to its wide-ranging interdisciplinary support. The multidisciplinary support from researchers in the academic, industry, and federal sectors. In 2001, the National Nanotechnology Initiative (NNI) launched its multiagency US government operation in 2001. It supports research and development, infrastructure, education, and commercialization of nanotechnology. According to the latest update in

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

March 2005, the 2006 NNI budget request, for nanotechnology research and development across the federal government is $1.05 billion .According to the NNI defines nanotechnology as the research that handles materials through measurement from 1 nanometre to 100 nanometers. New phenomena emerge as unique effects become observable when matter dimensions reach between 100 nanometers down to 1 nanometre. Nanotechnology spans the following main domains as part of its scope: Q. the divisions covered by nanotechnology extend across a wide range. Nanotechnology include fundamental nanoscale phenomena, Nanotechnology research and development across the federal government maintains a budget of $1.05 billion. Nanotechnology along with Nanomanufacturing and Societal Research of Nanotechnology benefits and risks make up the areas covered by nanotechnology practices. This review explores nanotechnology functions in medicine delivery and image acquisition systems. drug delivery and imaging. At present, 95% of all new most newly proposed therapeutic agents demonstrate inadequate drug distribution properties through the body. Biopharmaceutical properties. Therefore, there is a need the creation of appropriate drug delivery platforms must be developed for therapeutic distribution purposes. therapeutically active drug molecule only to the site of the system distributes drugs precisely to their targets without causing damage to healthy parts of the body. Nanotechnology exists as an essential component for therapy advancements. [1]

TABLE 1: Nano Scale System for Drug Delivery[1,2]

Drug Delivery System	Stage of Development	Limitation of Use	Example of Application
Liposomes	Marketed	Preparation steps have to be carefully controlled to achieve reproducible properties such as size and entrapment efficiency	Amphotericin B
Phospholipid	Preclinical	Limited stability in aqueous medium compared to other micelle types	Diazepam
Pluronic	Clinical Preclinical	Some monomers have not been tested in humans	Doxorubicin
Poly (L-amino acid)	Clinical in vitro	Immune response may increase with diversity in amino acids used. Biodegradability of Poly (amino acids) requires validation	Antisense oligonucleotides
Polyester	Preclinical	Polyester degrades by hydrolysis to produce acid metabolites that in excess may not be desirable	Doxorubicin

The development of nanomedicines for the future depends on this situation. Reduce therapeutic dose requirements and enhance new medicines' safety profile and therapeutic indexes when this technology becomes reality. This development would nanomedicines help both expand therapeutic values and increase safety aspects of future medications. therapeutics. Nanomedicines function as delivery systems when defined according to their size range between 1 to 100 nanometers in the nanometer size range (preferably 1 to 100 nm). [1] These systems contain drugs or imaging agents in encapsulated form or dispersed manner or adsorbed state or conjugated form. This review will concentrate on Nanomedicines exist as delivery systems suitable

for system-based intravenous drug delivery. parenteral routes. The dimensions of nanomedicines span across a specific range including. The delivery systems enable direct needle insertion which prevents the occlusion of needles or capillaries. Medical imaging and targeted drug delivery find suitable applications with these systems due to the pathophysiology of certain disorders such as cancer and inflammation.

TABLE 2: Nanoscale System for Imaging[2]

Drug delivery system	Stage of development	Technique	Contrast agent
Liposomes	Preclinical	MRI	Gadolinium
Quantum dots	Preclinical	fluorescence	Quantum dots
Magnetic nanoparticles	Clinical preclinical	MRI	Iron oxide-dextran

CLASSIFICATION OF NANOPARTICLES (NPs)[3-5]

As addressed, NPs are classified into three categories, organic, inorganic, and carbon based, with each of these having their advantages and disadvantages.

1. Organic Nanoparticles

Organic nanoparticles are primarily composed of carbon-based molecules and are engineered for biocompatibility and biodegradability. They often include materials such as:

- **Polymeric Nanoparticles:** These are made from synthetic or natural polymers like polylactic acid (PLA), polyglycolic acid (PGA), or their copolymer (PLGA). Their tunable degradation rates make them ideal for controlled drug delivery, as they can release encapsulated drugs in a sustained manner over time.
- **Liposomes:** Comprised of phospholipid bilayers, liposomes can encapsulate both hydrophilic and hydrophobic drugs. Their structural similarity to cell membranes enhances compatibility with biological systems, making them particularly useful in targeted therapy and reducing systemic toxicity.
- **Micelles and Solid Lipid Nanoparticles:** Formed from amphiphilic molecules, these nanoparticles self-assemble in aqueous environments. They improve the solubility of poorly water-soluble drugs and provide another means for controlled release.

Organic nanoparticles are favored in pharmaceutical and biomedical applications because they are generally less toxic, can be readily engineered for specific functions, and degrade into non- harmful metabolites once their job is done.

2. Inorganic Nanoparticles

Inorganic nanoparticles are made from metals, metal oxides, or semiconductors, and they typically exhibit unique optical, magnetic, or electronic properties. Common examples include:

- **Metallic Nanoparticles:** Gold, silver, and platinum nanoparticles are prominent in both diagnostic and therapeutic applications. For example, gold nanoparticles are used in imaging contrast and photothermal therapies due to their customizable optical properties.
- **Metal Oxide Nanoparticles:** Titanium dioxide (TiO_2), zinc oxide (ZnO), and iron oxide nanoparticles offer functionalities such as photocatalysis, UV protection, or magnetic

properties. Iron oxide nanoparticles, for instance, serve in magnetic resonance imaging (MRI) enhancement and targeted drug delivery.

- **Semiconducting Nanoparticles:** Quantum dots belong to this group. They exhibit unique luminescence properties that are useful for high-resolution imaging and sensing applications because their emission spectrum can be finely tuned by altering their size.

These inorganic materials are valued for their robustness, stability, and the precision with which they can be tailored for specific applications in electronics, catalysis, and medicine. However, their biocompatibility and long-term toxicity are areas of active research.

3. Carbon-Based Nanoparticles

Carbon-based nanoparticles harness the versatile and robust nature of carbon structures. They include:

- **Fullerenes:** These are spherical carbon structures (like the buckyball, C_{60}) known for their ability to act as antioxidants. Their unique structure allows them to scavenge free radicals, making them potential candidates in anti-aging and neuroprotective applications.
- **Carbon Nanotubes (CNTs):** CNTs are cylindrical nanostructures with remarkable strength, electrical conductivity, and thermal properties. They can be functionalized with various molecules, making them useful in drug delivery, biosensors, and even tissue engineering.

These carbon-based systems are celebrated for their high surface area and ability to be modified chemically, thus providing a wide range of functionalities for diverse applications beyond medicinal use—extending into areas like energy storage and advanced electronics.

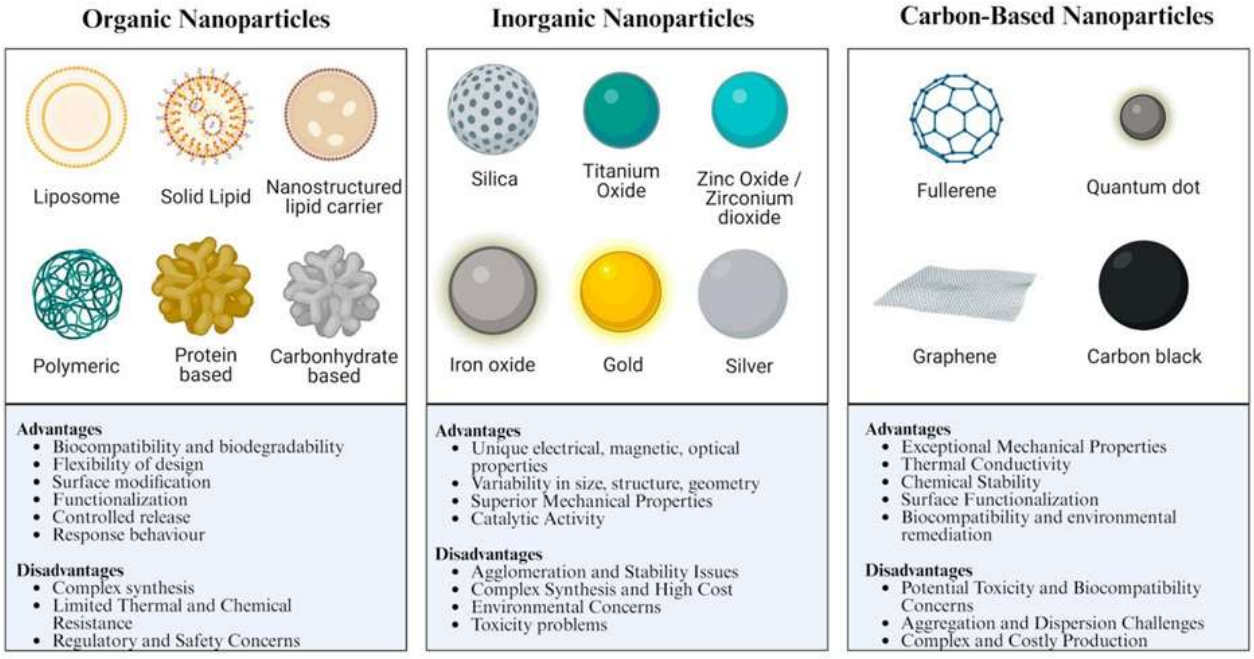

FIG. NO. 1 – TYPES OF NANOPARTICLES

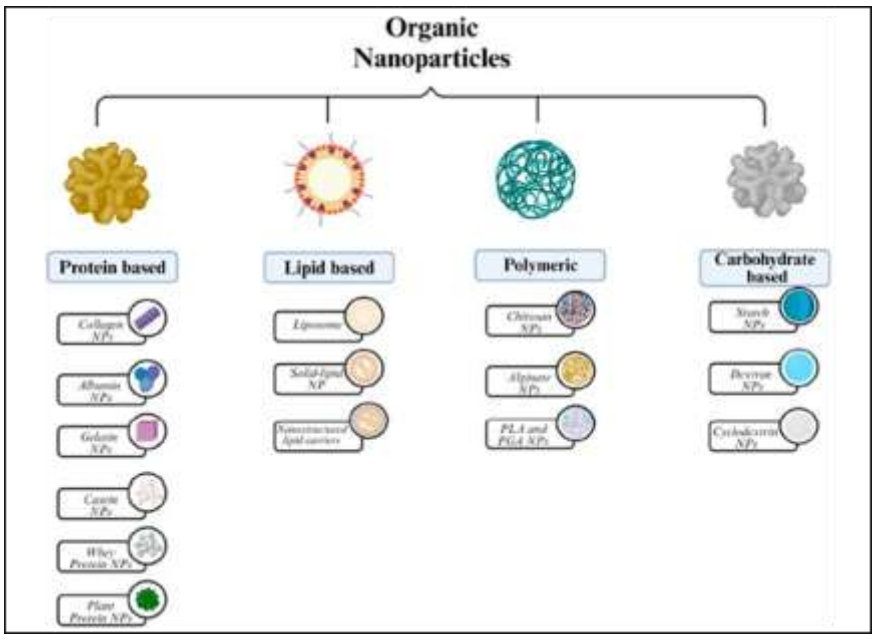

FIG NO. 2 – ORGANIC NPs

DESIGN OF NANO TECHNOLOGY – BASED DRUG DELIVERY SYSTEM[6,7]

The site of disease receives targeted drug delivery through nanoparticles. The placement of disease sites enables better absorption of drugs that do not dissolve well. Drugs, the targeting of drugs to a specific site, and drug bioavailability. A schematic comparison of the comparison between untargeted and targeted drug delivery platforms appears in Figure 2. Several anti-cancer drugs including paclitaxel Scientists have developed formulations of doxorubicin and 5-fluorouracil and dexamethasone and paclitaxel which use nanomaterials Pharmacologists have developed PLGA and PLA nanoparticles for encapsulating dexamethasone as a glucocorticoid drug product. The chemotherapeutic agent dexamethasone shows both anti-proliferative character and anti-inflammatory properties. Dexamethasone attaches itself to receptors within cellular cytoplasm before the formation of drug-receptor complexes. The drug moves inside the nucleus after nuclear translocation because of the following gene expression effect. The expression of particular genes responsible for cell proliferation occurs following receptor binding. The system provides sustained drug delivery of higher amounts which lasts for an extended period. The drug application completely stopped cell growth in vascular smooth muscle cells. The use of micelles or nanoparticles in cancer therapy receives extensive scientific research. The effectiveness of smaller sizes of drug delivery systems account for their effectiveness. The systems release medication at precise intervals while decreasing medication side effects. The failure rate of chemotherapy treatment exceeds acceptable limits because it is unable to eradicate cancer. Some tumor cells become resistant to multiple anticancer drugs which makes it difficult to treat cancer. The development of resistance begins when cancer cells start expressing the protein known as p-glycoprotein during most instances. The anticancer drug pumping capacity belongs to p-glycoprotein. The protein p-glycoprotein works to remove drugs from cells just as fast as they enter through the outer cell membrane. Research findings demonstrate nanoparticles possess the ability to transport anticancer drugs inside cells despite avoiding activation of the p-glycoprotein pump. Scientists explored the in vivo effectiveness of paclitaxel

containing nanoparticles loaded with the drug. Scientists demonstrated how placing paclitaxel inside emulsifying wax nanoparticles enabled successful drug resistance therapy against human cancers. The insolubility problems affecting paclitaxel become workable by using specific methods. The substance attains better effectiveness when albumin binds to it. Abraxane proves highly effective as a bio-compatible protein-based treatment using albumin. The US Food and Drug Administration has approved an injectable nano-suspension as medical treatment for breast cancer patients. The previous formulation of paclitaxel used the solvent Cremophor-EL. Acute hypersensitivity reactions are caused by the current paclitaxel formulations through Cremophor-EL.The treatment strategy aims to decrease the possibility of adverse allergic events during paclitaxel administration. Patients need to take pre-medical steroids with anti-histamines before receiving paclitaxel through long-infusion procedures. Patients receive the drug treatment by slow infusion which lasts several hours. Chemical appending of paclitaxel to albumin provided an increased dosage capacity. Its absence of solvent erases exposure to solvent-associated toxic side effects.

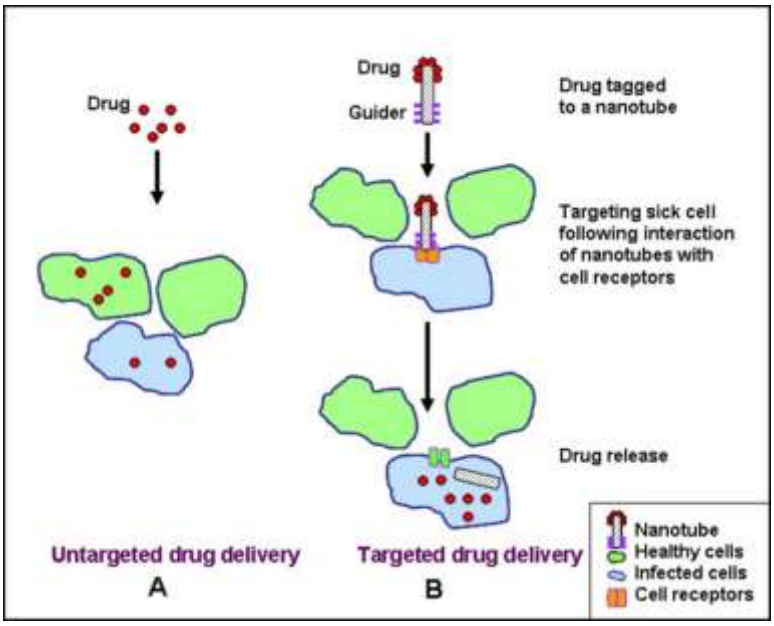

FIG. NO. 3 – NANOTECHNOLOGY BASED DRUG DELIVERY

Scientists explored the in vivo effectiveness of paclitaxel containing nanoparticles loaded with the drug. Scientists demonstrated how placing paclitaxel inside emulsifying wax nanoparticles enabled successful drug resistance therapy against human cancers. The insolubility problems affecting paclitaxel become workable by using specific methods. The substance attains better effectiveness when albumin binds to it.Abraxane proves highly effective as a bio-compatible protein-based treatment using albumin. The US Food and Drug Administration has approved an injectable nano-suspension as medical treatment for breast cancer patients. The previous formulation of paclitaxel used the solvent Cremophor- EL. Acute hypersensitivity reactions are caused by the current paclitaxel formulations through Cremophor-EL. The treatment strategy aims to decrease the possibility of adverse allergic events during paclitaxel administration. Patients need to take pre-medical steroids with anti-histamines before receiving paclitaxel through long-infusion procedures. Patients receive the drug treatment by slow infusion which lasts several

hours. Chemical appending of paclitaxel to albumin provided an increased dosage capacity. Its absence of solvent erases exposure to solvent-associated toxic side effects. Medical research revealed that Abraxane generated approximately double the reaction success rates compared to other treatments. The researchers examined the effects of paclitaxel loaded nanoparticles in treating human colorectal tumors inside living organisms. Static research demonstrated how emulsifying wax nanoparticles protect paclitaxel from drug resistance in the human colony 15 cell line. Scientists solved the paclitaxel insolubility issues through their discovery. The drug achieves enhanced delivery when it is implemented with albumin. Paclitaxel drug efficacy can be improved through binding it to albumin (Abraxane) which acts as bio-compatible proteins. An injectable nano-suspension exists as an approved medicine for breast cancer treatment. Experimental data demonstrates that solvent Cremophor-EL suffered from excessive use during previous formulations of paclitaxel. When using paclitaxel in formulations it produces acute hypersensitivity reactions. When receiving paclitaxel doses patients must take pre-medication with steroids and anti-histamines followed by a long infusion period. As a standard safety practice when delivering paclitaxel patients must first receive anti-histamine treatments with steroid medications while using extended infusion time. Medicating with anti-histamines and steroids precedes drug administration through extended infusion periods of several hours. Albumin paclitaxel treatment enabled higher medication delivery at a diminished infusion duration. The absence of solvent makes the treatment free of toxic solvent effects. In Phase III During the clinical trial Abraxane proved to be twice as effective in achieving treatment responses when compared to Taxol.

APPLICATION OF VARIOUS NANOCARRIERS FOR DIAGNOSIS AND TREATMENT

CANCER[8,9]

Targeting Cancer Cells With Nanoparticles

Medical experts identify cancer as among the toughest diseases which currently exist. Brain cancer stands as one of the most challenging types of cancer to find and properly manage because it creates obstacles for delivery of diagnostic and therapeutic elements across the blood-brain barrier. The challenges of brain cancer detection and treatment stem from the barrier that makes it difficult for agents to enter the brain. Therapeutic and imaging agents struggle to penetrate through the blood-brain barrier toward the brain. Nanoparticles demonstrate capability to deliver such agents within areas. Transmission of drugs through the blood-brain barrier was proposed to occur via Apolipoprotein E. Loperamide exists outside the blood-brain barrier since it cannot pass though this membrane barrier. After manual brain injection loperamide produces antinociceptive effects. Scientists loaded the drug loperamide into human serum albumin nanoparticles then connected it to apolipoprotein E. The antinociceptive effects caused by IV administration of this complex were observed in mice through the tail-flick test. The delivery system demonstrated successful treatment effects. Lipoprotein receptor identification defines the effectiveness of the treatment course. The researchers of Kopelman created Probes Encapsulated by Biologically Localized Embedding (PEBBLE) to function as the delivery system. These particles can combine with multiple unique agents and additional functions on their external surfaces Surface-embedded immobilized probes would direct the PEBBLE toward the target site. An additional component would assist in

identifying the target through imaging mechanisms. Researchers use magnetic resonance imaging to track targets which become the focus of the development. One component attached to the PEBBLE functions as a destructive delivery mechanism. Use of the drug or toxin at an appropriate level allows targeted release to surrounding cancer cells. All three capabilities can be condensed into one small polymer sphere for These microscopic particles combine into formidable cancer treatment instruments. Drugs containing doxorubicin bound to polysorbate-coated nanoparticles break through the intact blood-brain barrier to reach therapeutic levels within the brain tissues. The brain receives therapeutic amount of medicine from this delivery system. Superparamagnetic iron oxide nanoparticles function as smart conjugates The technique provides the ability to detect brain tumors at earlier stages and precisely pinpoint their location. Nanomaterial demonstrates remarkable promise as an agent to transport drugs for cancer cell targeting.

Targeting Angiogenesis With Nanoparticles

Strong angiogenesis promotes high aggression in tumor growth patterns. Starving tumor cells represents a fundamental approach for angiogenesis inhibition. Angiogenesis is regulated the system functions through multiple complex mediators as recent research demonstrates. Evidence suggests that both integrin αvβ3 and vascular endothelial growth factors maintain control over angiogenesis. Regulation of vascular development is performed by VEGFs and other factors. A novel anti-angiogenesis treatment strategy aims at selective targeting of αvβ3 integrin and VEGFs. The strategy uses anti-angiogenesis treatment to target many diverse solid tumors. Nanoparticles receive their surface treatment through coating. Melanoma cells recognize these particular peptides because they focus on binding specifically with αvβ3 integrin. Studies indicate that synthetic ArgGly-Asp (RGD) sequence shows selective binding to the αvβ3 integrin exists on endothelial cells throughout the tissue's blood vessels. These blood vessels create the potential to restrict. Hydrophobic modifications enable glycol chitosan to create self-aggregated nanostructures after completion of the modification process. Hydrophobic modifications of self-aggregated nanotube structures have been developed into a drug delivery platform. Studies have shown how the RGD peptide reacts with fluorescein isothiocyanate (FITC-GRGDS).

FITC-GRGDS seems potential for observing and disrupting the angiogenic tissue/blood vessels which surround tumor tissue. Our research group investigates the biological effects of RGDSK self-assembling rosette nanotubes (RGDSK-RNT). Recent scientific research has isolated these rosette nanotubes as a new nanotube class. Bioderived water-soluble nanotubes represent this new class of structures which form naturally after synthesis [28,29]. The formation of these nanotubes happens through the use of a building system based on guanine-cytosine motif. The unique feature ofRNT features the capability to bond with different functional group types. The G/C motif at the nanotube location endows functional adaptability to each structure. Nanotechnology researchers utilize specific medical or biological features of nanotubes for individual medical purposes. The RNTs have potential to undergo modifications. RNTs demonstrate the potential to capture different therapeutic molecules inside living bodies for medical treatment of cancer and inflammatory diseases.

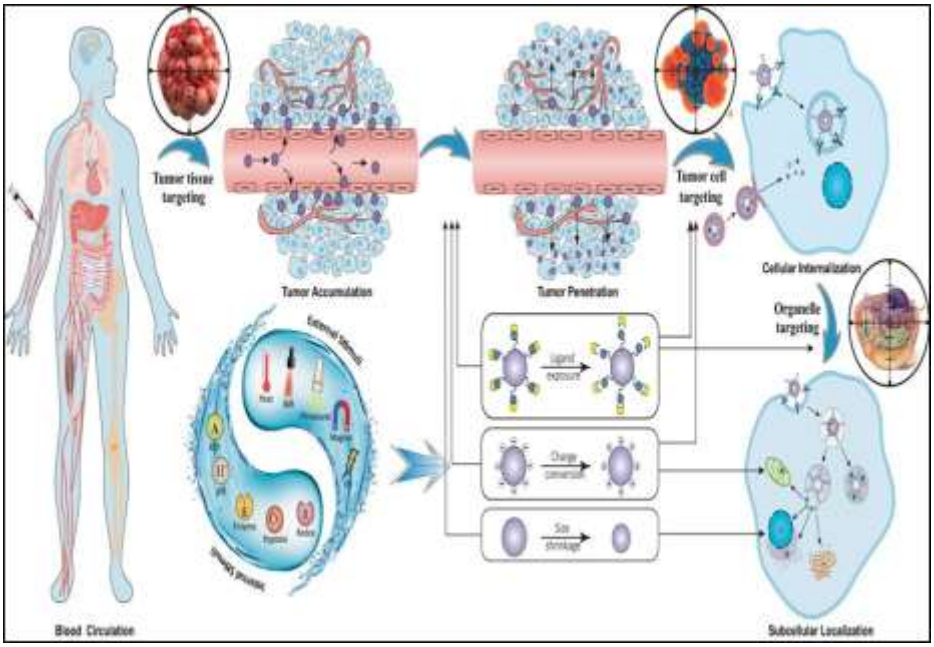

FIG. NO. 4 – NANOMEDICINES IN CANCER

NANOSYSTEMS IN INFLAMMATION[1-2]

Targeting Macrophages To Control Inflammation

The ability of macrophages to rapidly eliminate foreign particles leads to a rational Scientists developed a targeted method for nanoparticles to reach macrophages directly. Due to their secreted inflammatory mediator profile macrophages control the inflammatory responses in different medical conditions. Pharmaceutical research focuses on macrophages as target cells to combat numerous human diseases alongside their animal equivalents. The destruction process of microorganisms through macrophages reaches a level that is considered effective. Several microbial organisms including Toxoplasma gondii, Leishmania sp, Mycobacterium tuberculosis and Listeria monocytogenes have acquired resistance against phagocytosis activity of macrophages. These pathogens convert components of macrophage cellular mechanisms which function to destroy pathogens. Various microorganisms transform lysosomes into new housing when they survive the macrophage killing process. The delivery of antimicrobial agents into intracellular vacuoles containing pathogens inside macrophages function through nanoparticles. The use of macrophages shows promise for removing areas with infected cells [30,31]. A therapeutic drug concentration can be reached inside infected vacuoles using this delivery system. The method uses macrophages while simultaneously decreasing side effects experienced during drug delivery. The drug administration method releases pro-inflammatory cytokines after administering the drugs into systems. The delivery of antileishmanial drugs using Polyalkylcyanoacrylates (PACA) nanoparticles functions as a drug targeting system. Certain nanostructures made in similar designs could serve as effective targeting mechanisms.

Scientists developed the antifungal and anti-leishmanial agent amphotericin B.Scientists have developed lipid-based nanotube complexes with AmB to produce a less harmful version of this agent. Research led to creating a reduced toxic formulation of AmB through its complexation with lipids-based nanotubes. Gupta and Viyas developed trilaurinAmB liposomes as emulsomes

stabilized by phosphatidylcholine soya using nanosized lipid particles for formulation. Researchers developed a novel formulation of intravenous macrophage-targeted drug delivery through nanotubular lipids. Research into nanoparticles carrying toxins provides robust potential to eliminate undesirable macrophages. The elimination of unwanted macrophages remains crucial during gene therapy and in treating autoimmune blood diseases along with T cell-mediated diabetes along with rheumatoid arthritis and neural system conditions after angioplasty procedures. Nanoparticles have shown effectiveness in treating arthritis along with spinal cord injury and sciatic nerve injury and restenosis after angioplasty. Exploitation of nanoparticles with lethal properties for macrophages remains a viable alternative. Patents have proved to be more effective than targeting a single type of macrophage cell receptor as a treatment method for nanocarrier antigen delivery and targeting.

Targeting Inflammatory Molecules

During the last twenty years multiple cell adhesion molecules surfaced for discovery. The cell surface contains glycoproteins called receptors these proteins serve as receptors that connect cells to each other along with cells to the extracellular matrix. The cell adhesion molecules group into four parts which are integrins cadherins selectins and T-cell receptors. The four molecular types integrate under the term integrins cadherins selectins and these. Efficient inflammatory cell movement requires these molecules. Inflamed organs attract neutrophils and monocytes through their passage across the bloodstream Substantial research supports the notion that excessive migration of Neutrophil movement into inflamed lungs generates excessive tissue destruction. Scientists work intensively to optimize neutrophil migration into inflamed tissues. Research on the understanding of this domain has experienced significant advancements in recent times. Recent developments regarding cell adhesion molecules have revolutionized the design procedures of pharmaceutical products. The scientific research has resulted in the identification of therapeutic peptides and proteins for treating cancer and other diseases affecting the heart and autoimmune system. Several molecular complexes perform essential functions during diseases. Scientists use peptides to guide their targeting of both αvβ3 and αvβ5 integrin receptors. The intercellular adhesion property produces therapeutic peptides that serve as derivatives. The intercellular adhesion molecule-1 (ICAM-1) has been applied to target the αvβ2. Researchers have successfully attached cycle RGD peptide structurestumor- targeted delivery systems using these drugs receive significant enhancement through these systems. Research involved mice that received human breast carcinoma cells inside their bodies. The administration of MDA-MB-435 cells to patients led to survival benefits after receiving. All of the control mice that received no treatment died as a result of the disease yet survival rates improved in mice treated with Dox-RGD4C.The tumor vasculature displays αvβ3 and αvβ5 integrins which serve as targets during angiogenesis.

Several points where Extracellular regulated kinases (ERK) control apoptosis and cell survival exist. The activation of p53 and BAX leads to increased action through augmented caspase-3 and The peptide promotes increased activities of caspase-3 and caspase-8 while simultaneously lowering Akt activity and enhancing TNF-α expression. Our team investigates how RGD-RNT targets αvβ3 integrins through P38 kinase signalling pathways which affect human lung epithelial cells and bovine and Equine neutrophil migration. Researchers studied this peptide in human lung epithelial cells together with bovine

and Equine neutrophil migration. A fragment of peptide known as cLABL peptide originates from the I-domain section of The α subunit of Leukocyte Function-Associated Factor-1 produces cLABLpeptideultimate through the coupling of methotrexate to ICAM-1.Scientists have linked methotrexate (MTX) with this peptide (cLABL)to create MTXcLABL conjugate. The peptide participates in tissue inflammatory reactions and numerous cancer processes. The drug directing potential of this conjugate makes it applicable for targeting inflammatory along with tumor cells. MTX shows its anti-inflammatory action by blocking the release of anti-inflammatory cytokines including (interleukin-6) IL-6 and (interleukin-8) IL-8.The research evaluated MTX-cLABL conjugate performance against MTX in blocking the secretion of cytokines including IL-6 and IL-8 by human coronary artery endothelial cells treated with TNF-α.The suppression of IL-6 production occurs more efficiently with MTX-cLABL than typical MTX applications. In addition recent research shows that PLGA nanoparticles coated with cLABL peptides exhibit these same functions.

More research is needed to understand the cellular pathways through which cell adhesion molecules enter cells and travel within them. Drug molecules use cell-adhesion molecules as delivery pathways to specific cells. Researchers use the increased expression levels of ICAM- 1 to detect specific cell types and establish cancer and other disease diagnoses (heart and autoimmune diseases).

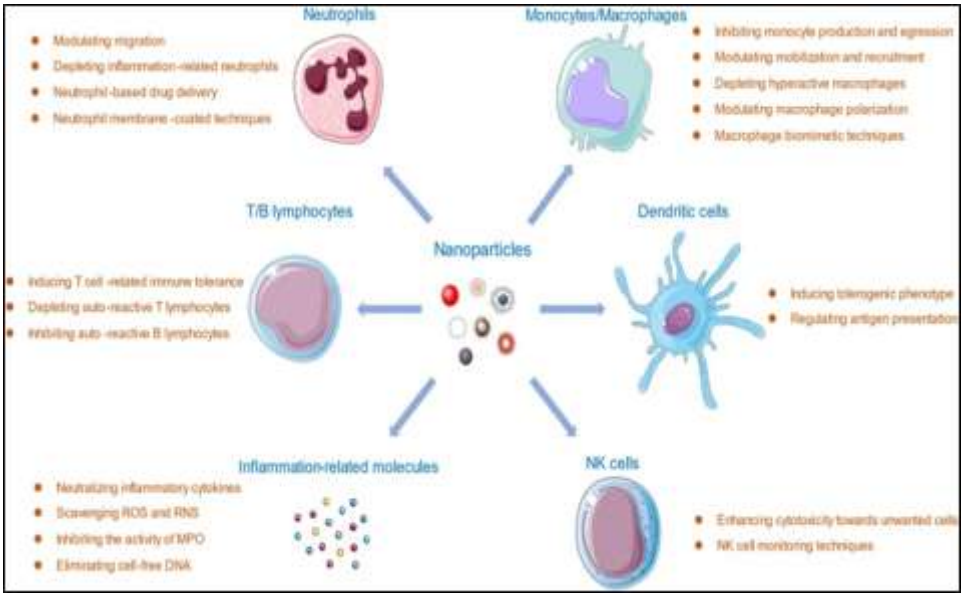

FIG. NO. 5 – NANOMEDICINES IN THE TREATMENT OF INFLAMMATORY DISEASES

NANOMEDICINES IN DIABETES MANAGEMENT[3,4]

Nanomedicine in diabetes management represents a novel interdisciplinary approach that integrates nanotechnology with pharmaceutical sciences to overcome traditional challenges in diabetic care. At its core, nanomedicine utilizes nanoparticles and nanoscale delivery systems to improve the bioavailability, targeting, and controlled release of therapeutic agents. This innovative strategy seeks to mimic physiological processes more accurately—such as the dynamic regulation of insulin secretion—and thereby enhance treatment outcomes for both type 1 and type 2 diabetes. Nanoparticles can be engineered to be glucose-sensitive, meaning they release insulin only when glucose levels exceed the optimal range, closely

mimicking the natural function of pancreatic β-cells. This smart drug release behavior reduces the risk of hypoglycemia and offers patients a more physiologically sound method of insulin administration. For example, researchers have developed formulations where the nanoparticles swell or change structure in response to hyperglycemia, triggering insulin release with remarkable precision. One of the most promising aspects of nanomedicine is its ability to transform insulin delivery. Traditional subcutaneous injections often cause discomfort, inconvenience, and, in some cases, localized infections. In contrast, oral nano formulations are being designed to protect insulin from the harsh gastrointestinal environment and promote its uptake via the gut. This approach not only eliminates the pain associated with injections but also offers a more natural route of drug administration that can improve patient adherence and quality of life.

Beyond insulin delivery, nanomedicines can serve as platforms for gene and cell therapies aimed at restoring or enhancing β-cell function. Nanoparticles can carry oligonucleotides or other genetic materials to target cells, stimulating endogenous insulin production or modulating immune responses, particularly in autoimmune-driven type 1 diabetes. This mechanism also minimizes potential immunogenicity compared to viral vectors, offering a safer alternative to traditional gene delivery systems. Nanomedicine also plays a critical role in addressing diabetic complications. In the context of diabetic wound healing, nanoparticles loaded with regenerative molecules can be locally administered to stimulate cell repair and tissue regeneration. This local delivery minimizes systemic exposure while ensuring a sustained release of bioactive agents, which accelerates the healing process and reduces the risk of infection. Similarly, for diabetic nephropathy—a severe complication leading to end-stage renal disease—nanocarriers have been explored to improve the pharmacokinetic profiles of therapeutic molecules. These nanostructures help in precise targeting and sustained release, thereby enabling early intervention and potentially mitigating renal damage. Moreover, nano formulations have been extensively studied for the treatment of type 2 diabetes, where challenges such as drug solubility, rapid clearance, and off-target effects need precise management. Nanostructure-based delivery systems—including polymeric nanoparticles, solid lipid nanoparticles, nanostructured lipid carriers, and liposomes—improve the stability of anti-diabetic agents and allow for controlled release. These formulations not only enhance drug efficacy but also reduce side effects, which is critical for chronic conditions like type 2 diabetes that demand long-term treatment.

Despite the promising data, nanomedicines in diabetes management also face significant challenges. Manufacturing complexity, potential nanoparticle toxicity, regulatory hurdles, and the need for large-scale clinical validation remain areas needing further research. However, ongoing advancements in nanofabrication techniques and a deeper understanding of nano-bio interactions are gradually addressing these hurdles, paving the way for translating these technologies from the lab bench to clinical practice. In summary, nanomedicine offers a multifaceted platform to enhance the management of diabetes by providing more effective, targeted, and safer therapeutic modalities. Its applications range from smart insulin delivery to advanced gene therapy and improved treatment of complications, signifying a transformative step forward in diabetic care. Looking ahead, further integration of nanotechnology with personalized medicine could tailor treatments even more precisely to the individual's metabolic profile, ultimately

revolutionizing the landscape of diabetes management. There's also growing interest in exploring combinatorial treatments where nanomedicines are used alongside traditional therapies to achieve synergistic effects. If you're curious, we can delve deeper into the design of specific nanocarriers, emerging clinical trial results, or the mechanisms behind the stimuli-responsive behavior of these nano systems.

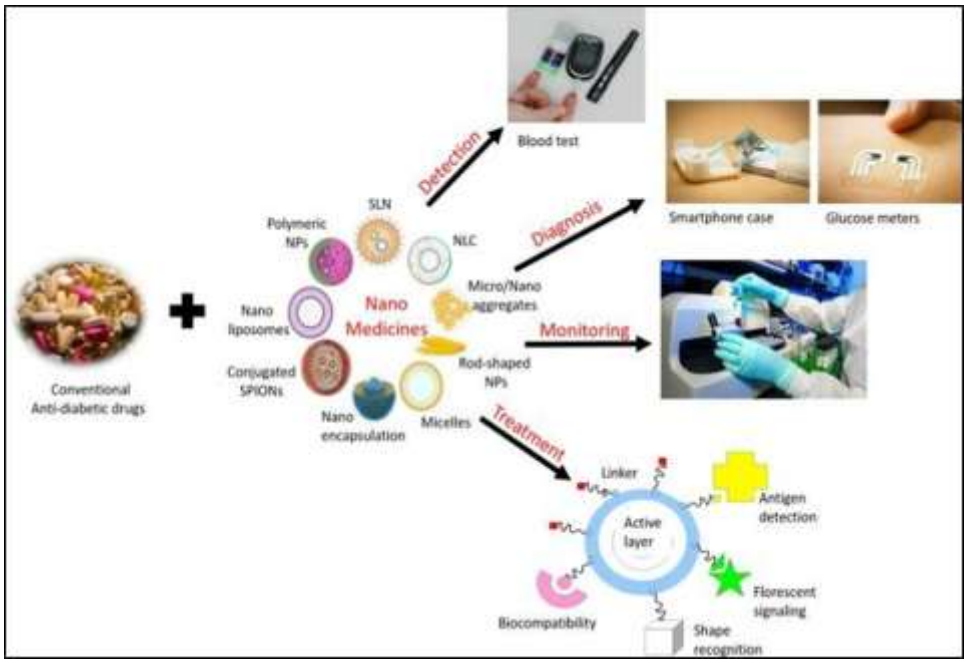

FIG. NO. 6 – NANOMEDICINES IN DIABETES MANAGEMENT

NEUROLOGICAL DISEASE CONTROL USING NANOPARTICLES[5-7]

Nanomaterials are emerging as powerful tools in the control and therapy of neurological diseases due to their unique ability to cross the blood–brain barrier (BBB), target specific brain regions, and offer controlled drug release mechanisms. Neurological disorders—such as Alzheimer's disease, Parkinson's disease, Huntington's disease, stroke, and traumatic brain injury—are often characterized by complex pathologies including oxidative stress, inflammation, and aberrant protein accumulation. Nanomaterials offer the promise of addressing these multifaceted issues by providing a means to deliver therapeutic agents directly to the affected areas while minimizing systemic side effects.

Overcoming the Blood–Brain Barrier

One of the paramount challenges in treating neurological conditions is the BBB, which tightly regulates the movement of substances into the brain. Nanomaterials, by virtue of their size and modifiable surface properties, can be engineered to traverse this barrier efficiently. Strategies such as surface functionalization with ligands that target endothelial receptors or coating with biodegradable polymers enhance the passage and accumulation of nanocarriers in the brain tissue. This targeted approach not only improves drug concentration at the intended site of action but also reduces harm to peripheral tissues.

Targeted Drug Delivery and Controlled Release

Nanomaterials can encapsulate a variety of therapeutic molecules—ranging from small-molecule drugs to peptides and nucleic acids—and

protect them from premature degradation. For instance, nano formulations can be designed to release their cargo in response to specific stimuli, such as pH changes or the presence of reactive oxygen and nitrogen species (RONS). In neurodegenerative diseases where oxidative stress is a critical pathological component, nanomaterials that mimic natural oxidoreductases can neutralize RONS and attenuate redox stress. This precise, stimuli-responsive release profile increases therapeutic efficacy and minimizes the dosage required, thereby reducing the risk of systemic toxicity.

Addressing Intracellular Pathologies

Many neurological diseases are characterized by intracellular events like protein aggregation or mitochondrial dysfunction. Nanomaterials can be tailored to target intracellular compartments—for example, directing antioxidants or gene-silencing agents to mitochondria or lysosomes. By gaining entry into specific cell types such as neurons or glial cells, these nano systems can modulate disease-specific pathways directly. Research into nanoparticles that can deliver RNA interference molecules or CRISPR components for gene editing is already paving the way towards targeted molecular therapies for conditions like Huntington's disease and certain forms of dementia.

Combating Oxidative Stress and Inflammation

Oxidative stress and chronic inflammation are key drivers in the pathology of a variety of neurological disorders. Nanomaterials, including cerium oxide nanoparticles and fullerenes, have been shown to possess intrinsic antioxidant properties. These particles act by scavenging free radicals and emulating the action of endogenous antioxidant enzymes. This not only provides neuroprotection by reducing oxidative damage but also modulates inflammatory cascades, potentially slowing the progression of neurodegeneration. Studies have documented the promising role of such nanomaterials in alleviating redox stress, a crucial element in the treatment of diseases like Alzheimer's and Parkinson's.

Safety, Toxicity, and Future Directions

Despite the significant potential, the clinical translation of nanomaterial-based therapies faces several hurdles. One of the primary concerns remains nanotoxicity; the long-term effects of these materials within neural tissues require rigorous investigation. Additionally, manufacturing scalability, regulatory oversight, and comprehensive preclinical evaluations are essential for ensuring safety and efficacy. Current research is actively addressing these challenges by developing biodegradable nanomaterials and optimizing their physicochemical characteristics to balance therapeutic benefits with potential risks.

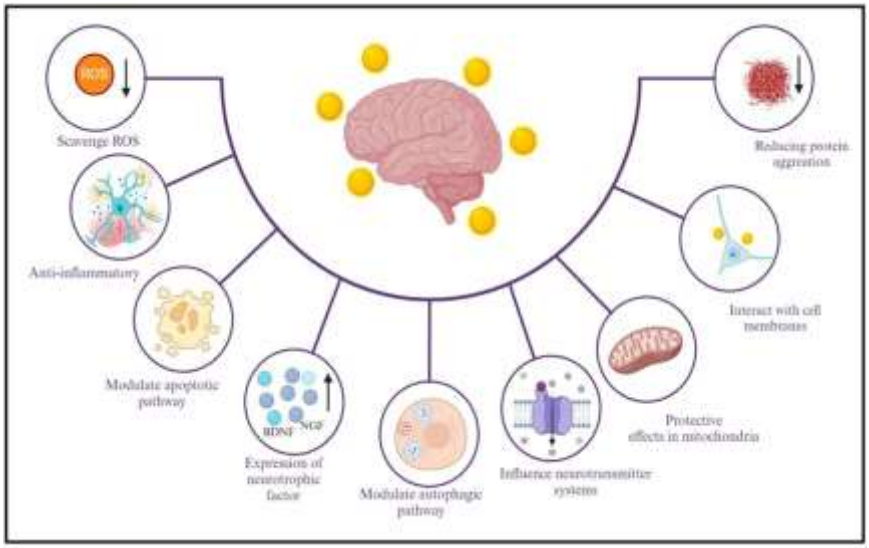

FIG. NO. 7 – NANOPARTICLES IN NEUROLOGICAL DISORDERS

NANOMEDICINES IN CARDIOVASCULAR DISEASES[8,9]

Nanomedicines in cardiovascular diseases represent a paradigm shift in how we can diagnose, treat, and manage conditions that remain the leading cause of death globally. By integrating nanotechnology with pharmaceuticals, researchers are developing sophisticated nano systems that can overcome several limitations of conventional therapies, improve targeting, and minimize adverse effects.

Targeted Delivery and Controlled Release

One of the most significant advantages of nanomedicines is their ability to deliver therapeutic agents precisely where they are needed. For instance, nanoparticles can be engineered with surface modifications—such as ligands or antibodies—that specifically recognize biomarkers expressed on atherosclerotic plaques or damaged cardiac tissue. This targeted approach not only increases the concentration of the drug at the desired site but also significantly reduces systemic toxicity. Furthermore, these nano systems can be tailored for controlled release, ensuring a steady therapeutic level over time rather than a rapid spike that conventional drugs might produce.

Theranostics: Combining Therapy with Diagnostics

An exciting development in this field is the concept of theranostics, where a single nanoplatform is used both for treatment and diagnosis. Nanoparticles designed for theranostic applications can carry imaging agents alongside therapeutic drugs. This dual functionality allows clinicians to monitor the progression of the disease in real time while administering treatment, thereby enabling a more personalized therapy. For instance, magnetic nanoparticles have been investigated for their ability to serve as contrast agents in magnetic resonance imaging (MRI) while at the same time facilitating targeted drug delivery through magnetic guidance.

Diverse Nanomaterial Platforms

Various nanomaterial platforms are being explored for cardiovascular applications, including:

- **Polymeric Nanoparticles:** These particles are popular due to their excellent drug encapsulation and controlled-release properties. They can be designed to degrade safely in the body, minimizing long-term accumulation.
- **Liposomes:** Often used to encapsulate both hydrophobic and hydrophilic drugs, liposomes facilitate targeted delivery and can reduce off-target effects.
- **Dendrimers:** With their highly branched structures, dendrimers provide high loading capacities and precision in targeting molecular interactions, which is key in preventing platelet aggregation and thrombosis.
- **Magnetic Nanoparticles:** These can be directed to specific areas within the cardiovascular system using external magnetic fields. Their use in remote magnetic drug targeting represents a promising avenue for treating localized conditions such as myocardial infarction.

Addressing Complex Pathologies

Cardiovascular diseases such as atherosclerosis and myocardial infarction are complex disorders characterized by inflammation, oxidative stress, and lipid accumulation. Nanomedicines offer several strategies to address these pathologies:

- **Anti-inflammatory and Antioxidant Therapy:** Nanoparticles can be loaded with drugs specifically designed to reduce inflammation and oxidative stress in the vascular tissues. This localized delivery reduces the risk of systemic side effects often seen with traditional anti-inflammatory drugs.
- **Prevention of Thrombosis:** In cases of thrombosis, targeted nanomedicines can help dissolve clots or prevent their formation by delivering anti-thrombotic agents directly to the affected regions.
- **Restoration of Tissue Function:** Some nanoplatforms are being developed to not only deliver drugs but also to promote tissue repair and regeneration, an essential aspect for patients recovering from myocardial infarction or other cardiac injuries.

Challenges and Future Directions

Despite these promising strategies, several challenges remain in the clinical translation of nanomedicines for cardiovascular diseases. Issues such as long-term toxicity, large-scale manufacturability, and regulatory hurdles must be addressed. Researchers are actively working on developing biodegradable nanomaterials and refining targeting mechanisms to ensure that these approaches are both safe and effective in the long run. The integration of advanced imaging techniques with nano-drug delivery is expected to further enhance the management of complex cardiovascular conditions, paving the way toward more personalized and precision- based therapies.

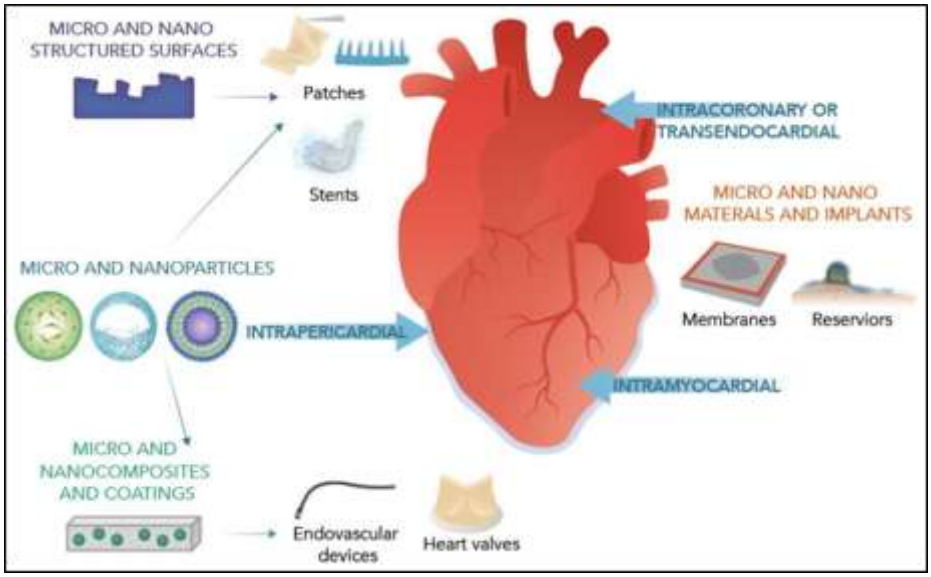

FIG. NO. 8 – NANOMEDICINES IN CARDIOVASCULAR DISEASES

NANOMEDICINES IN RESPIRATORY DISEASES[2]

Nanomedicines offer a transformative approach to treating respiratory diseases by overcoming many limitations of conventional therapies and enabling precise, targeted delivery of therapeutics to the lungs. Their design is optimized to navigate the complex pulmonary environment, overcome natural barriers such as mucus and alveolar defense mechanisms, and allow for controlled drug release at the disease site.

Enhanced Drug Delivery and Targeting

One of the primary advantages of using nanomedicines in respiratory disorders is their ability to improve drug solubility and stability while protecting sensitive therapeutics from enzymatic degradation. This is especially relevant for inhalable formulations designed to target the lungs directly. By engineering nanoparticles—such as polymeric nanomaterials, liposomes, nanosuspensions, and dendrimers—with specific surface modifications, researchers can enhance penetration through the mucus barrier and achieve targeted delivery within the pulmonary system. This means lower systemic doses, reduced side effects, and enhanced local therapeutic effects for conditions like asthma, chronic obstructive pulmonary disease (COPD), lung infections, and even lung cancer .

Overcoming Biological Barriers and Stimuli-Responsive Release

Nanomedicines are uniquely capable of navigating biological hurdles that conventional drug formulations face. Their size and engineered surface properties enable them to better traverse respiratory barriers, ensuring that drugs reach the lower respiratory tract where many diseases manifest. Additionally, certain nanoparticles can be designed to respond to specific triggers such as pH changes, redox conditions, or inflammatory markers. These stimuli-responsive designs allow for the controlled release of therapeutics only when and where they are needed, thereby enhancing efficacy while minimizing off-target effects. For example, in pulmonary infections or inflammatory conditions like acute lung injury, these smart nanocarriers can release anti-inflammatory or antimicrobial agents directly at the site of damage, improving clinical outcomes.

Applications in Various Respiratory Disorders

Recent research demonstrates the extensive potential of nanomedicine across a spectrum of respiratory diseases:

- **Asthma and COPD:** Inhalable nanoparticle formulations have been shown to enhance the delivery of corticosteroids and bronchodilators, ensuring rapid onset of relief with sustained local release. This targeted strategy not only improves therapeutic efficacy but also mitigates the systemic side effects typically associated with these drugs.
- **Pulmonary Infections:** Nanocarriers can encapsulate antimicrobial agents and deliver them directly to infected lung tissues. By concentrating the drug at the infection site, these approaches improve pathogen eradication while reducing the development of drug resistance.
- **Lung Cancer:** Nanomedicine offers dual functionalities—enabling both imaging (theranostics) and therapy. Nanoparticles can carry chemotherapeutic agents along with imaging markers to allow real-time tracking of drug delivery and tumor response, thus enhancing personalized treatment strategies.
- **Pulmonary Fibrosis and Acute Respiratory Distress Syndrome (ARDS):** By modulating local inflammation and oxidative stress, nanomedicines are being explored as a means to slow the progression of fibrotic changes and improve lung function in these conditions. Their ability to deliver antioxidants and anti-fibrotic agents directly to affected tissue is a particularly promising avenue for future therapies .

Challenges and Future Directions

Despite promising preclinical results, several challenges remain in translating nanomedicine to widespread clinical use in respiratory diseases. Issues related to large-scale manufacturability, long-term biocompatibility, and potential nanotoxicity must be rigorously addressed. Current studies are focusing on the development of biodegradable and biocompatible nanomaterials that can safely deliver drugs over prolonged periods. Additionally, regulatory pathways are being refined to better accommodate the unique properties of nanocarriers, paving the way for their future clinical application. Nanomedicines in respiratory diseases showcase an exciting frontier in pulmonary therapeutics—a field where precision, controlled release, and targeted delivery converge to offer new hope against some of the most challenging respiratory conditions.

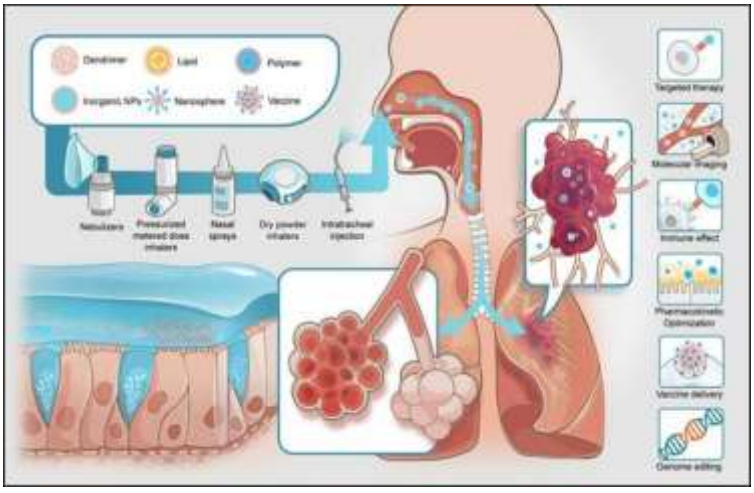

FIG. NO. 9 – NANOPARTCLES IN RESPIRATORY DISORDERS

THE LIMITATIONS/CHALLENGES OF NANOTECHNOLOGY[1-3]

Nanotechnology has opened up transformative possibilities across multiple sectors, but its application is accompanied by several key limitations and challenges.

Safety and Toxicity Concerns

One of the major challenges of nanotechnology is managing the health risks associated with nanoscale materials. Nanoparticles have a high surface area to volume ratio, which often leads to enhanced chemical reactivity. This can result in unpredictable interactions when nanoparticles enter biological systems. For example, some nanomaterials may induce oxidative stress, inflammatory responses, or even cellular damage when inhaled, ingested, or absorbed through the skin. Additionally, the long-term effects of chronic exposure to these materials, both for users and manufacturing workers, remain under investigation. The potential for unforeseen toxicological impacts necessitates comprehensive risk assessment and monitoring strategies throughout the lifecycle of nanomaterials .

Scalability and Manufacturing Challenges

While many nanomaterials have been successfully synthesized in the laboratory, scaling up production to meet industrial and commercial demands presents significant challenges. Manufacturing nanoparticles with consistent size, shape, and surface properties is complex. Variability in these attributes can lead to differences in functional performance and safety. Moreover, many synthesis methods involve expensive reagents, strict environmental controls, or energy-intensive processes that add to production costs. Overcoming these factors is critical to transition nanotechnologies from small-scale research to large-scale application reliably and economically .

Regulatory and Standardization Hurdles

Currently, regulatory frameworks for nanotechnology are still evolving. The unique properties of nanomaterials often do not fit neatly into existing regulatory categories developed for bulk materials. This creates challenges in classifying, testing, and approving nano-enabled products. Regulators must balance promoting innovation with protecting public health and the environment. Establishing standardized testing protocols for toxicity, environmental impact, and long-term safety is essential, yet remains a work in progress. These regulatory ambiguities can delay the intentional design and deployment of nanotechnologies in various fields .

Environmental Impact and Waste Management

The environmental implications of nanotechnology are another significant concern. Nanoparticles released during manufacturing, use, or disposal can accumulate in ecosystems, potentially harming wildlife and disrupting biological processes. Their small size allows them to penetrate soil, water, and air sediments, posing challenges for traditional waste management methods. Effective strategies are required to track, recover, and recycle nanomaterials to minimize ecological disruption and avoid contamination of natural resources.

Economic and Ethical Considerations

The high costs associated with nanotechnology research and production can limit its accessibility, leading to disparities between advanced and developing economies. Ethical issues also arise regarding the long-term impacts of nanomaterials

on human health and the environment, informed consent in medical applications, and equitable access to the benefits of nanotechnology. These economic and ethical challenges must be addressed through interdisciplinary collaboration, inclusive policymaking, and transparent risk communication.

In summary, while nanotechnology holds tremendous potential, overcoming these limitations requires coordinated efforts in research, regulation, and public engagement. Addressing safety and toxicity, achieving scalable production, developing clear regulatory standards, mitigating environmental impacts, and considering economic and ethical issues are all critical to unlocking the full promise of nanotechnology.

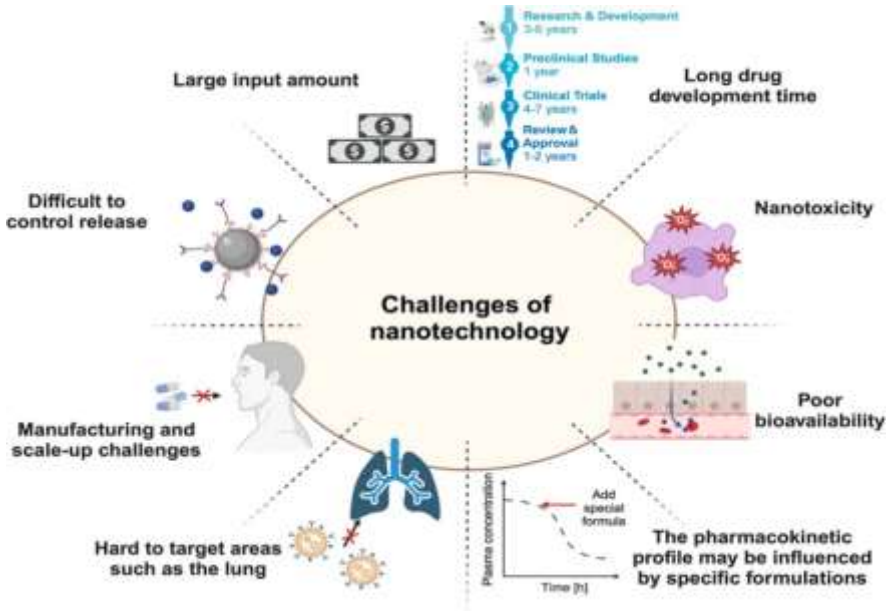

FIG. NO. 10 – LIMITATIONS OF NANOTECHNOLOGY

DISCUSSION

In recent years, targeted drug delivery using nanotechnology has emerged as a groundbreaking approach to optimize therapeutic outcomes while minimizing adverse effects. Nanocarriers— such as liposomes, polymeric nanoparticles, dendrimers, and inorganic nanomaterials—enable the precise delivery of drugs to diseased tissues, enhancing efficacy and reducing the risks associated with conventional systemic therapies. A significant advantage of these nanocarriers is their ability to overcome biological barriers. By modifying the nanoparticle surface with ligands, antibodies, or peptides, researchers can design systems that selectively bind to specific receptors on target cells. This active targeting not only increases the local drug concentration at the desired site but also minimizes exposure to healthy tissues and lowers systemic toxicity. Moreover, the enhanced permeability and retention (EPR) effect further aids the passive accumulation of nanoparticles in areas with leaky vasculature, such as tumors, thereby amplifying the therapeutic action. Another innovative aspect is the incorporation of stimuli-responsive mechanisms. Nanocarriers can be engineered to release their drug payload in response to environmental triggers—like pH shifts, temperature changes, or enzymatic activity—specific to the disease microenvironment. This controlled release capability ensures a sustained therapeutic effect

and a reduction in dosing frequency, both of which are critical for chronic conditions.

Despite these promising benefits, several challenges remain. Ensuring nanoparticle stability and reproducibility during large-scale manufacturing is complex. Additionally, there are concerns regarding long-term toxicity and unpredictable in vivo biodistribution, which necessitate comprehensive preclinical and clinical evaluations. Navigating regulatory frameworks also poses significant hurdles, as conventional guidelines often fall short in addressing the unique properties of nanomaterials. Overall, targeted drug delivery through nanotechnology represents a dynamic convergence of engineering, biology, and medicine. Continued research in nano–bio interactions and advanced synthesis methods will be vital for realizing its full potential. As innovations progress, these tailored delivery systems are expected to play a pivotal role in the evolution of personalized medicine, ultimately enhancing patient care while minimizing unwanted side effects.

CONCLUSION

The incorporation of nanotechnology in drug delivery systems has been a major revolution in contemporary therapeutics. By facilitating site-specific drug delivery to targeted cells or tissues, especially in the cure of cancer, infections, and chronic diseases, nanocarriers like liposomes, dendrimers, nanoparticles, and nanotubes have significantly enhanced the efficacy, bioavailability, and safety profiles of numerous drugs. This strategy reduces systemic side effects, improves therapeutic efficacy, and enables controlled and long-term drug release. In spite of the present limitations like scalability, long-term safety, and regulatory challenges, ongoing developments in nanotechnology and biomedical research are leading the way to more efficient, targeted, and patient-centric treatments. In summary, nanotechnology-based targeted drug delivery systems are a promising and developing area of pharmaceutical science with the capability to transform disease management and enhance quality of life for patients across the globe.

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HOW TO CITE: Syed Mahfuz Islam, Targeted Drug Delivery System Using Nano Technology, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 7, 2257-2278. https://doi.org/10.5281/zenodo.15974987