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A REVIEW ON NANOTECHNOLOGY AND ITS APPLICATIONS

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ABSTRACT

Nanotechnology plays a significant role in the field of medicine and in drug delivery, mainly due to the major limitations affecting the conventional pharmaceutical agents, and older formulations and delivery systems. The effect of nanotechnology on healthcare is already being felt, as various nanotechnology applications have been developed, and several nanotechnology-based medicines are now on the market. Nanotechnology is attracting more and more funding from the public and business sectors in many parts of the world. The majority of conventional drug-delivery systems (CDDSs) feature a high, instantaneous drug release following administration, which increases the frequency of administration. As a result, a lot of research has been done all over the world on the creation of pharmaceutical nanomedicines that can be turned into goods produced by regional pharmaceutical firms. The worldwide pharmaceutical market and healthcare system are expected to be significantly impacted by pharmaceutical nanomedicine products. Furthermore, a brief discussion will be held regarding the significance of nanotechnology in the creation of pharmaceutical products, the optimal characteristics of nanocarriers, the causes of the failure of certain nanomedicines, and the critical factors in the development of nanomedicines.

Keywords: Nanotechnology Pharmaceutical Nanomedicines; Nanoparticles; Drug Delivery

INTRODUCTION

The latest and most promising drug delivery technique is the application of nanoparticles. A 'carrier' is employed to carry the drugs to the different sites in the body. The carrier has to be able to release the drug at a certain rate based on the requirement of the target tissue. The carrier has to be able to store the medicine until the time it reaches the target site, at which it has to release the drug. Nanoparticles are the only means by which anything is achievable. [1,2]

The drug is administered into the patient after being bound to the nanoparticle. Since the nanoparticle is released at the site of action, the drug may be absorbed, metabolized, or eliminated in the body. [3] All this is regulated by modifying the chemical composition and surface characteristics of the nanoparticle. Compared to the conventional injection-based drug delivery, the application of nanoparticles has a number of benefits. It maximizes and extends therapeutic effects, reduces side effects, enhances drug accumulation in the target tissue, and protects the drug from degradation.[4]

With the advancement of nanotechnology, more drug delivery systems such as lipid-based, injectable, gene-based, and site-specific systems are rapidly shifting towards nanoparticle-based delivery. This lies at the center of medical delivery in the future. [5]

A revolutionary change in medical and health care therapy is made possible by the technological advances of manipulating material at the nanoscale. Today, there is an unexpected increase in the application of nanoparticles in a wide range of fields, from molecular biology to physics and inorganic and organic chemistry, medicine, and material science.[6] Nanoparticles play an ever-growing role in biological applications as they connect molecular design (<1 nm) with bulk material (1 mm). Due to their unique properties—such as their small size and high surface areas—nanoparticles are capable of interacting with biological systems in significantly different ways than larger-scale materials. In addition, there are several nanoparticle modifications that make chemical and surface properties of the particles controllable.

They are nanospheres, nanocapsules, and polymer or metal colloids. Last but not least, nanoparticle systems can be rendered biodegradable in the body or functionalized or tagged to be targeted to selectively to certain parts of the body through a biological system. Such potential benefits over other molecular delivery systems of comparable size, e.g., liposomes, are a promising field of study of nanoparticle drug delivery. [7]

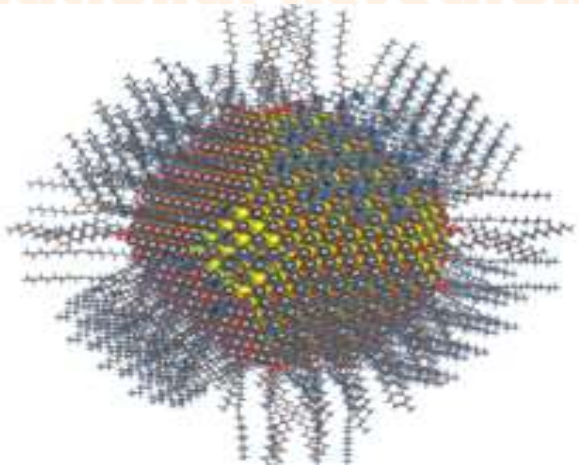

Fig 1: NANOPARTICLES

Applications for Diagnosis

Nanotechnology has made inroads into medical imaging and diagnostics during this decade. Quantum dots

allowed for accurate fluorescence imaging of cells and tissues, whereas superparamagnetic iron oxide nanoparticles (SPIONs) were first used as MRI contrast agents.

Significant Advances in Pharmacy and Nanotechnology
Milestone for the year

Year	Milestone
1959	Richard Feynman's lecture introduces the concept of molecular manipulation.
1974	Term "nanotechnology" is coined by Norio Taniguchi.
1980s	Development of liposomes and early nanocarriers.
1995	FDA approves Doxil, the first nanomedicine.
2005	Abraxane approved for cancer treatment.
2020	Pfizer-BioNTech and Moderna mRNA vaccines approved using lipid nanoparticles.

The History of Nanotechnology

The roots of nanotechnology date back to 1959, when physicist Richard Feynman gave his now-celebrated lecture, "There's Plenty of Room at the Bottom." There, he suggested that the direct manipulation of atoms and molecules might give rise to useful nanoscale technologies. Feynman's idea, while entirely theoretical at the time, set the stage for the eventual scientific revolution to follow.

Scientists started examining how such concepts could be used in medicine during the 1970s and 1980s. Norio Taniguchi was the initial individual who used the term "nanotechnology" to refer to the manipulation of molecules and atoms with the precision needed in semiconductor technology in 1974.

The First Nano-Drug Transporters: Liposomes

The creation of liposomes in the 1960s was the actual beginning of the intersection of pharmacy and nanotechnology, but the use of liposomes as drug nanocarriers did not become fashionable until the 1980s and 1990s. Liposomes are one of the first instances of pharmaceutical nanotechnology since they are spherical vesicles made of phospholipid bilayers between 50 and 200 nm in size.

Doxil, the initial liposomal preparation of the chemotherapeutic agent doxorubicin, was approved by the FDA in 1995. Doxil demonstrated the way the EPR effect of nano-encapsulation could enhance drug solubility, reduce toxicity, and enhance tumor cell targeting.

FDA-Approved Nanomedicines

Nanomedicine research escalated at an exponential rate in the 2000s. A number of nano-formulations were utilized in the therapeutic context:

Approved in 2005, Abraxane is an albumin-bound formulation of paclitaxel used to treat breast cancer without subjecting patients to toxic solvents.

AmBisome: Amphotericin B in liposomal formulation which is employed against fungal infections. An approved liposomal irinotecan for pancreatic cancer is Onivyde.

These medications showed how nanocarriers can enhance bioavailability, lower toxicity, and boost patient compliance.

Personalized and Targeted Treatments Currently, nanotechnology is employed for cancer immunotherapy using siRNA or checkpoint inhibitors delivered by nanoparticles.

treatments that target the brain with nanoparticles that can pass through the blood-brain barrier.

systems that react to stimuli, such temperature-sensitive liposomes or pH-sensitive micelles.

Nanoparticles are currently a crucial component of point-of-care (POC) diagnostic systems, allowing for quick testing for illnesses like COVID-19, HIV, and malaria.

2. CLASSIFICATION OF NANOPARTICLES

The nanoparticles are usually categorized into the organic, inorganic and carbon based nanoparticles. Organic nanoparticles Dendrimers, micelles, liposomes, or ferritin, etc. are commonly known as organic nanoparticles or polymers. Organic nanoparticles are biodegradable, non-toxic, and some particles such as micelles and liposomes contain a hollow core known as nano capsules and are sensitive to thermal and electromagnetic radiation such as heat and light [8]. Because of these special properties, organic nanoparticles are an ideal option for drug delivery. Beyond their normal unique characteristics, such as size, composition, surface shape, etc., the drug carrying capacity, stability and the way drugs are performed whether entrapped or adsorbed are the are of uses and/or efficiency. The biomedical sector uses these organic nanoparticles most typically, as part of the medication delivery system, as they are effective and because they could be administered in particular portions of the body referred to as targeted drug delivery.

Inorganic nanoparticles

Inorganic nanoparticles are particles that are not made up of carbon. Metal and metal oxide- based nanoparticles are generally categorised as inorganic nanoparticles.

• Metal based

Metal-based nanoparticles may be made in a constructive or destructive sense by synthesizing metal down to their nanometric size. Almost all metals can be synthesized into nanoparticles. The metals mostly synthesizing into nanoparticles include aluminum (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag) and zinc (Zn). The unique characteristics of nanoparticles include their size, usually 10-100 nm, surface characteristics, such as because of their small size, they can possess a high surface area to volume ratio, pore sizes, surface charge, and surface charge density, shape, characteristics such as crystalline or amorphous morphology, spherical or cylindrical shape, color, reactivity, sensitivity to environmental triggers, heat, moisture, sunlight, and air.

• Metal oxide based

To alter the characteristics of their respective metal-based nanoparticles, metal oxide nanoparticles are prepared. Iron (Fe) nanoparticles spontaneously oxidize in room temperature to iron oxide (Fe_2O_3) when they come in contact with oxygen, and hence they are more reactive than iron nanoparticles. Their primary reason for synthesis is their higher efficiency and reactivity [10]. Aluminum oxide (Al_2O_3), cerium oxide (CeO_2), iron oxide (Fe_2O_3), magnetite (Fe_3O_4), silicon dioxide (SiO_2), titanium oxide (TiO_2), and zinc oxide (ZnO) are the most produced. Unlike their metal counterparts, these nanoparticles have been of an excellent quality. Carbon-based

Carbon nanomaterials are materials made up entirely of carbon [11]. Fullerenes, graphene, carbon nanotubes (CNT), carbon nanofibers, carbon black, and sometimes nanoscale-activated carbon are some of their forms.

METHODS OF SYNTHESIS OF NANOPARTICLES

The nanoparticles are synthesised by various methods that are categorised into bottom-up or top- down method**.**

Bottom-up method

The accumulation of material from atoms to clusters to nanoparticles is known as the bottom-up or constructive process. Spin, pyrolysis, chemical vapour deposition (CVD), sol-gel, and biosynthesis are the most popular bottom-up techniques for producing nanoparticles.

- **Sol-gel**

The sol– a colloidal phase of solids within a liquid phase. The gel – a solid macromolecule immersed in a solvent. Sol–gel is the most commonly used bottom-up technique, due to its ease of use and ability to create most nanoparticles. This is a wet chemical method which makes use of a chemical solution as a precursor to an integrated system of discrete particles. Some of the most common precursors in the sol–gel process are metal oxides and chlorides [12]. Once the precursor is dispersed in a host liquid (usually by sonication, shaking or stirring) the final system is in both a liquid and solid phase. Nanoparticles are harvested through phase separation by various methods including, sedimentation, filtering, centrifugation, and moisture is removed through drying [13].

• Spinning

Nanoparticles are prepared by spinning in a spinning disc reactor (SDR). It is a rotating disc inside a reactor or chamber to allow physical parameters like temperature to be controlled. The reactor is normally filled with nitrogen or other inert gases to remove oxygen and avoid chemical reactions. The disk is spun with an oscillating speed while water and precursor are introduced. Spinning condenses atoms or molecules together, and the resulting solution is precipitated, harvested, and dried [14].

• Biosynthesis

Biosynthesis is a safe, environmentally friendly method of producing nontoxic, biodegradable nanoparticles [16]. Unlike traditional methods which rely on chemicals for bio reduction, capping, etc., biosynthesis uses bacteria, plant extracts, fungi, etc. along with the precursors to produce nanoparticles. Because of their special and enhanced characteristics, biosynthesised nanoparticles are suitable for biological applications [15].

Top-down method

Destructive or top-down approach is the reduction of the size of a particle of a bulk material to the nanometric scale. Sputtering and thermal decomposition, nanolithography, laser ablation, mechanical milling are some of the most widely used techniques of nanoparticle synthesis.

• Mechanical milling

Mechanical milling is the most used top-down method to create different types of nanoparticles. Mechanical milling is used for milling and an-nealing nanoparticles when different elements are ground in inert atmospheres during syn-thesis [17]. In the mechanical milling method, plastic deformation can define the shape of the particles, fracture reduces size, and cold-welding increases size.

• Nanolithography

The development of nanometric scale structures with one dimension of 1 and 100 nm is the objective of nanolithography studies. Numerous types of nanolithography exist, including optical, electron-beam, multiphoton, nanoimprint, and scanning probe lithography [18]. Transfer printing of a given shape or structure on a light-sensitive material by etching material in a controlled manner to create the desired shape and structure is known as lithography. The creation of clusters of desired size and shape from a single nanoparticle is one of the most significant advantages of nanolithography. Disadvantages include the cost and need for sophisticated equipment [19].

• Laser ablation

Laser Ablation Synthesis in Solution (LASiS) is a common method for generating nanoparticles using a range of solvents. When a laser beam strikes a metal, immersed in a liquid solution, a plasma plume condenses and produces nanoparticles [20]. LASiS represents a more dependable top-down technique for producing metal-based nanoparticles, as opposed to the typical approach of chemical reduction of metals. LASiS is also a "green" method as there are no chemicals or stabilizing agents used in this process and nanoparticles can be stably produced in organic solvents and water.

• Sputtering

Sputtering is particle emission by ion collision to produce nanoparticles on the surface [21]. Annealing is most often performed after sputtering of a thin nanoparticle layer. Particle size and shape are affected by substrate material, annealing time and temperature, layer thickness, and others [22].

• Thermal decomposition

Heat breaks chemical bonds in a material, and this is called thermal decomposition which is an endothermic chemical breakdown [9]. The decomposition temperature is a specific temperature at which some element will chemically break down. The nanoparticles are formed by breaking down the metal at discrete temperatures and undergoing a chemical reaction that produces secondary compounds.

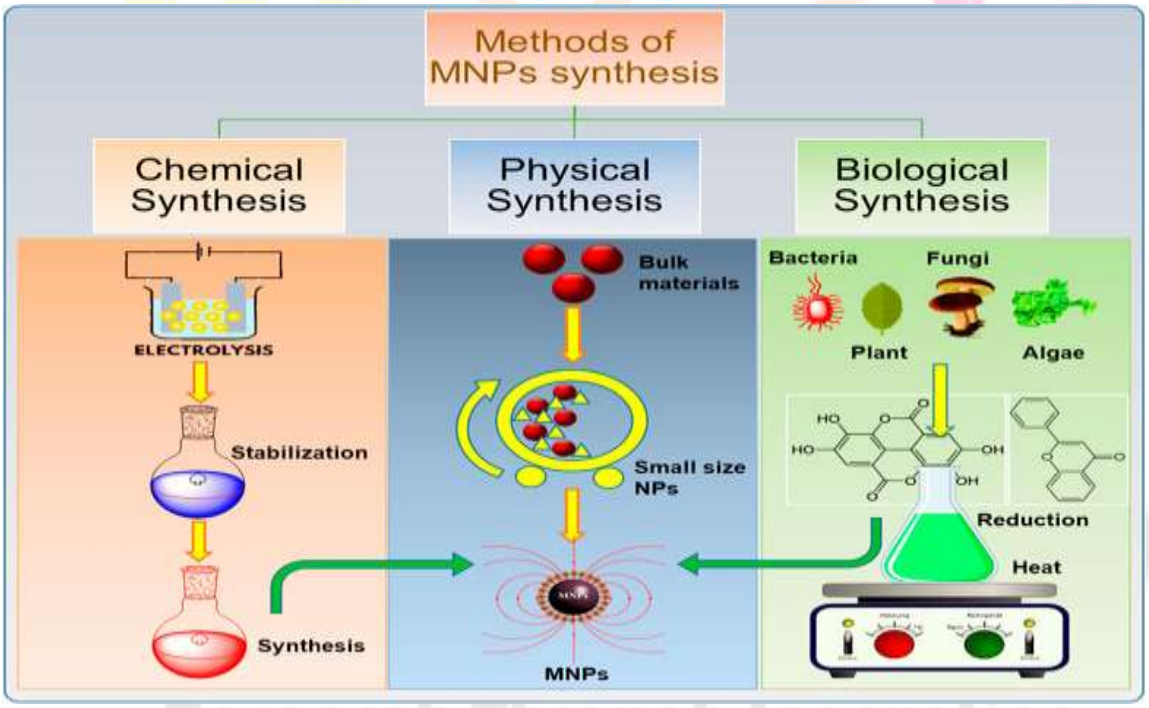

FIG: METHODS OF SYNTHESIS OF NANOPARTICLES

3. CHARACTERISTICS OF NANOPARTICLES

The unique characteristics determines the potential and application of a nanoparticle. The nanoparticle characterisation is carried out by various measurement techniques.

• Size

The particle is one of the most basic and most important metrics for defining nanoparticles. It determines if the particle is microscale or nanoscale, as well as the size and dispersion of the particle. The most common method of determining the size and dispersion of particles is electron microscopy. While solid-phase bulk materials are evaluated by laser diffraction, particles and clusters are investigated using images from scanning electron microscopes (SEM) and transmission electron microscopes (TEM) [23]. Particles in the liquid phase are characterized by both centrifugation and photon correlation spectroscopy. For particles in the gas phase, the methods of imaging particles are not only rude but also challenging; hence the use of Scanning Mobility Particle Sizer (SMPS) which is a more rapid and accurate measurement than the previous methods.

• Surface area

The surface area of another key element in the characterization of nanoparticles is also extremely important. The functionality and properties of a nanoparticle are greatly reliant on its surface area to volume ratio. BET analysis is the most widely used technique to measure surface area. A straightforward titration is appropriate for the measurement of the surface area of liquid phase particles, although it is a time-consuming process. NMR, nuclear magnetic resonance spectroscopy, is therefore employed. The differential mobility analyzer (DMA) and modified SMPS are used to measure the surface area of gaseous phase nanoparticles.

• Composition

Purity and activity of the nanoparticle depend on its elemental or chemical composition. In addition to lowering the activity of the nanoparticle, a high percentage of secondary or unwanted constituents is a source of contamination and a resultant reaction. X-ray photoelectron spectroscopy (XPS) is typically used to establish composition [24]. Wet chemical analysis, using ion chromatography, mass spectrometry, and atomic emission spectroscopy, is the second step in certain protocols, e.g., chemical digestion of the particles. Filtration or electrostatic collection is used to gather the gaseous phase particles, which are analyzed using spectrophotometric or wet chemical analysis [25].

• Surface morphology

Depending on the various forms and surface configurations of the nanoparticles, the use of its traits is mainly determined by the nanoparticles themselves. There are conical, spherical, flat, cylindrical, tubular, and irregular shapes among them; they can have crystalline or amorphous surfaces, or they can consistently decomposed. The surface is generally determined via an electron microscopy showing SEM and TEM [26]. Particles in the liquid phase are put down on a surface and searched, while particles in the gaseous phase are filtered and/or electrostatically restricted for an electron microscope image.

• Surface charge

The surface charge of a nanoparticle will determine its performance against a target. Surface charges and dispersion stability of solutions are generally measured by zeta potentiometers [27]. Nanoparticle charges in the gaseous phase can be measured by employing a Differential Mobility Analyzer (DMA).

• Crystallography

Crystallography is the study of the arrangement of atoms and molecules in crystalline solids. Nanoparticle crystallography uses either powder X-ray, electron, or neutron diffraction to determine the structural arrangement for crystal solids [26].

CHARACTERIZATION TECHNIQUES FOR NANOPARTICLES

Characterization techniques are essential for comprehension of the properties and behaviour of nanoparticles. They allow for characterization of nanoparticle size, shape, structure, composition, surface chemistry and interaction, which is essential for determining the best performance in various applications. As such, here are the explanations of some commonly utilized characterization techniques:

Electron Microscopy

- **Transmission Electron Microscopy (TEM):** TEM provides high-resolution images of nanoparticles, allowing visualization of their morphology, size, and internal structure at the nanoscale.[28]
- **Scanning Electron Microscopy (SEM):** SEM provides detailed surface morphology images of nanoparticles, offering information on particle size, shape, and surface features.[29]

X-ray Diffraction (XRD)

X-ray diffraction (XRD) provides information regarding the characteristics of nanoparticles including the crystal structure, phase purity, and crystallite size.

XRD analyses the diffraction pattern of X-rays scattered by the crystal lattice of nanoparticles, which provides evidence of these structural characteristics.[30]

Dynamic Light Scattering (DLS)

X-ray diffraction (XRD) provides information regarding the characteristics of nanoparticles including the crystal structure, phase purity, and crystallite size.

XRD analyses the diffraction pattern of X-rays scattered by the crystal lattice of nanoparticles, which provides evidence of these structural characteristics.[30]

Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR is used to look at the chemical composition and surface functional groups of nanoparticles. By determining the infrared light absorbed through molecular vibrations, FTIR provides information about surface chemistry, ligand binding, and functionalization of nanoparticles. [32]

UV-Visible Spectroscopy

The optical properties of nanoparticles may be characterized using UV-visible spectroscopy, specifically absorption and plasmon resonance. In terms of sensing, imaging, and photovoltaics application, it provides information on the concentration, size, and optical bandgap of nanoparticles. [33]

Zeta Potential Analysis

Zeta potential analyses can provide information on surface charge and stability by measuring the electrokinetic potential of nanoparticles in solution. Zeta potential is used to assess colloidal stability, aggregation, and dispersing state of nanoparticles across various processes. [34]

Thermogravimetric Analysis (TGA)

TGA examines thermal stability, composition, and mass changes of nanoparticles with temperature. It provides information on surface changes, the presence of organic coatings, and the temperature at which nanoparticles degrade. [35]

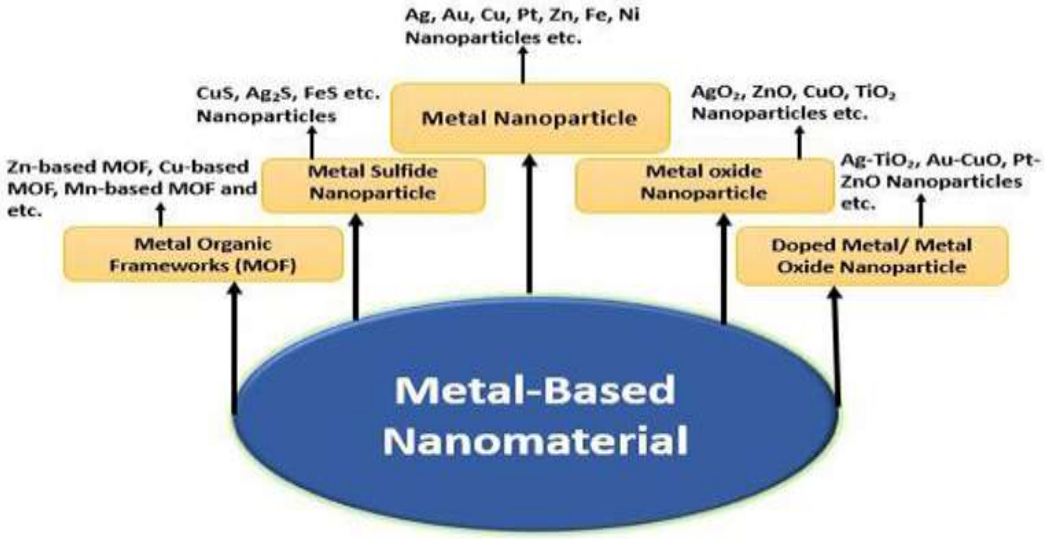

Fig 5: DIFFERENT CHARACTERISATION METHODS FOR NANOPARTICLES

4. SIGNIFICANT CHALLENGES IN NANOPARTICLE PRODUCTION

The amount of data and research on nanoparticles has increased exponentially in recent years with the emergence of nanotechnology. Not many of them make it to clinical trials. The majority of them make it only up to the in vitro and in vivo stage. Though every new nano formulation poses a different set of challenges regarding clinical translation, most NPs have similar kinds of issues that belong to three broad categories: biological, technical, and study-design related.

Lack of routes of administration, reduction of biodistribution, degradation of NPs, toxicity, and the route via which they pass through biological barriers are some of the biological barriers [36]. It is difficult for NPs to reside and interact with the target site since they are typically injected intravenously (IV) directly into the circulation. Hence, a highly concentrated drug is utilized, which may not show the desired therapeutic effect [37]. However, different in vivo and in vitro studies have established the use of 3D magnetic fields to control the movement of NPs opposite to the direction of blood flow, which could be overcome by using magnetic nanoparticles. However, more studies have to be conducted on the effect of magnetic fields on the human body, interaction of multiple magnetic fields, and high dose of NPs.

Scale-up synthesis, equal optimization, and performance prediction are some of the technological challenges with NPs. These are needed for ensuring NPs' clinical efficacy. Scaling up to bulk is not always possible due to equipment and other issues, and most of the NPs used in in vitro and in vivo studies are usually synthesized in small quantities. There is no systematic optimization of the lead clinical candidates that show optimal performance in animal models. To overcome this, we can use certain methodologies that can screen a large number of nano formulations and choose one optimum formulation through selected iterations [38,39,40]. However, such effects shouldn't be used directly in human trials.

It is hard to anticipate the effectiveness and performance of nanoparticles, and reproduction of human study results in vivo is extremely hard. Along with experimental data, theoretical or computational modeling simulating physiological tissues and environments can be established. For instance, research on organs-on-chips is ongoing and could improve NP prediction of effectiveness and performance.

Clinical research is greatly affected by study design issues, i.e., study size, objective, and when to give NP treatments. The majority of the research is conducted using "cell and animal models," which may not be of any benefit to human trials. Because of this, it is difficult to employ a single model to mimic actual physiological responses. Also, because metastasis is one of the most typical features of cancer, "models of cancer metastasis" also must be questioned severely. Furthermore, N = 1 clinical trials will be required if we are concerned with

individualized therapy. A myriad of factors must be taken into account, such as genetics, environment, and medical history. [41,42].

Restrictions:

1. **Toxicity and Biocompatibility**: Certain nanoparticles have the potential to build up in organs or trigger immunological responses.

Factor	Description	Toxicity Impact
Size	<100 nm particles can enter cells or cross the blood-brain barrier	Smaller NPs may penetrate tissues and organs
Surface Charge	Positive charge increases uptake	Cationic NPs may cause membrane disruption
Shape	Rods, spheres, etc interact differently with cells	High aspect ratio particles may induce inflammation
Material	Metals, polymers, lipids	Some materials (e.g., silver, cadmium) are cytotoxic
Surface Modifications	PEGylation, targeting ligands	May reduce opsonization but also alter biodistribution

2. **Regulatory Obstacles:** A major regulatory obstacle is the lack of a consensus definition for the terms "nanomaterial" and "nanomedicine." The criteria used by different agencies vary depending on their size, purpose, or makeup.

Agency	Definition Basis	Size Range (nm)
FDA (USA)	Structure or function significantly different at nanoscale	~1–100
EMA (EU)	Intentionally engineered with nanoscale features	~1–1000
ISO	Physical dimensions	1–100

3. **Manufacturing Complexity:** Because of the accuracy and control needed at the nanoscale, the production of pharmaceuticals based on nanotechnology, or nanomedicines, is extremely complicated. Manufacturing nanomedicines requires strict control over particle size, shape, surface chemistry, and stability, all of which have a substantial impact on safety and effectiveness, in contrast to traditional drug manufacture.

Challenge	Explanation	Impact on Product
Scale-up from lab to industry	Processes that work at small scales often fail at larger volumes due to heat, shear forces, or mixing inefficiencies	Inconsistent nanoparticle size or aggregation
Reproducibility	Maintaining consistent physicochemical properties batch-to-batch	Variable therapeutic outcomes
Stability	Nanoparticles may aggregate, oxidize, or degrade	Shortened shelf life or loss

5. APPLICATIONS OF NANOPARTICLES

Clinical Applications : Through the development of new diagnostic tools, enhanced drug delivery, and precision medicine, nanotechnology has revolutionized clinical practice. Nanomedicine lowers toxicity while increasing treatment efficacy in the pharmaceutical industry. A thorough summary of the clinical uses of nanotechnology is provided below, arranged by therapeutic area and technology.

1. Cancer Therapy : By facilitating precisely focused drug delivery, reducing harm to healthy cells, and enhancing treatment results, nanotechnology has completely transformed cancer therapy. Novel nanocarriers can improve solubility, extend circulation, overcome multidrug resistance, and deliver medications straight to tumor cells.

Mechanism	Description
Enhanced Permeability and Retention (EPR)	Tumor vasculature is leaky; nanoparticles accumulate more in tumors than in healthy tissues.
Active Targeting	Nanoparticles are functionalized with ligands (antibodies, peptides) that bind specifically to tumor cell receptors.
Stimuli-Responsive Release	Nanocarriers release drugs in response to pH, enzymes, or temperature changes within the tumor microenvironment.
Combination Therapy	Nanoparticles can co-deliver multiple agents (e.g., chemo + gene therapy) to enhance therapeutic outcomes.

2. **Neurological Disorders :** Crossing the blood-brain barrier (BBB) is a major obstacle for CNS drugs. Nanocarriers improve BBB penetration and target delivery.

Application	Nanotechnology	Disease
Curcumin nanoparticles	Polymeric nanoparticles	Alzheimer's disease
Liposomal Levodopa	Liposomes	Parkinson's disease
siRNA delivery systems	Lipid nanoparticles	Glioblastoma

Nanotechnology in Diagnosis : Since nanotechnology offers high sensitivity, specificity, speed, and downsizing, it has become a game-changing tool in medical diagnostics. Clinicians can create point-of-care (POC) diagnostic tools, track treatment outcomes, and identify diseases early by utilizing the special physical and chemical characteristics of nanoparticles.

Cancer Diagnostics

Technique	Nanomaterial	Cancer Type	Detection Method
Liquid biopsy	Magnetic nanoparticles	Prostate, breast	Isolate tumor DNA
Imaging	Gold nanoshells	Head & neck cancer	Near-infrared light absorption

Infectious Disease Detection

Test	Nanotech Used	Result Time
COVID-19 LFA	Gold nanoparticles	~15 minutes
TB biosensor	Magnetic + carbon nanocomposites	~30 minutes

• Cosmetics and Sunscreens

There are several advantages to using sunscreen with nanoparticles, such as titanium dioxide. Titanium oxide and zinc oxide nanoparticles can absorb and reflect ultraviolet radiation while not blocking visible light, which is why they are used in sunscreen products. Iron oxide nanoparticles are a pigment in some lipsticks [43].

• Electronics

Nanoparticles are being incorporated into display technology due to the growing demand for larger, bright displays found in today's televisions and computer monitors. For example, contemporary displays employ light emitting diodes (LEDs) using nanocrystalline lead telluride, cadmium sulfide, as well as zinc selenide and sulfide [44]. There is a growing need for portable consumer electronics such as laptops and cell phones that are small, lightweight, and with high-capacity batteries. Private nanoparticles are an excellent candidate for battery separator plates. Their foam-like (aerogel) structure allows for the storage of more energy than conventional batteries. Batteries made from nanocrystalline nickel and metal hydrides last longer and need less recharging, due to their large surface areas [45]. Nanoparticles are also used to detect gases such as NO2 and NH3, based on the increase in electrical conductivity of the nanoparticles [46]. As gas molecules bond to the nanoparticles, charge transfer from the nanoparticles to NO2 results in the expansion of pores, yielding a more effective gas sensor.

• Catalysis

Nanoparticles are more catalytically active due to greater available surface area. In addition, nanoparticles are excellent catalysts for aiding chemical synthesis due to their extremely high surface area to volume ratio [47]. Nickel catalysts in car catalytic converters, for example, are able to use less platinum due to their larger surface area which saves cost and increases efficiency. This is one of the primary applications of platinum nanoparticles. Nanoparticles can also be used in certain chemical reactions, such as the reduction of nickel oxide to nickel (Ni) metal.

• Medicine

Nanotechnology has taken advantage of nanoparticles for use in drug delivery, significantly advancing the medical realm. Nanoparticles can be utilized for delivering the drugs to specific cells [48]. Delivering the drug in the correct place and proper amount will reduce the total amount of drug needed to be ingested and the negative side effects that can occur. This approach can reduce the costs and overall negative consequences. Tissue engineering has the ability to replace traditional therapeutic approaches, like organ transplants, artificial implants. A scaffold made of carbon nanotubes for bone growth is one example of this [49]. There are various procedures that use gold. One drug to assist with memory improvement uses gold as a common example of a medication. Some medical applications utilize gold in order to improve an infant's state of mind [50].

• Food

Nanotechnology can improve food production, processing, preservation, and packaging. For example, in food packaging a nanocomposite coating can direct the injection of anti-microbial materials directly on the film surface during food packaging [51]. An example of this application is in using nanoscale vitamin and mineral nanodrops as a food additive in the production of canola oil.

• **Diagnosis**

For the diagnosis and treatment of a variety of cancers, a wide array of nanomaterials are being exploited with limited side effects to reliably image tumors and/or deliver drugs (theragnostic approach). Some of the nanodevices that have been developed for oncology applications include quantum dots (QDs), carbon nanotubes (CNTs), paramagnetic nanoparticles (NPs), liposomes, gold nanoparticles (GNPs), MRI contrast agents for intraoperative imaging, and novel NP-based methods for highly specific DNA and protein detection [52,53,54,55].

• **Dye Degradation**

The treatment of wastewater and its potential reuse depends on the removal of water contaminants from water bodies, such as cationic dyes, acid dyes, azo dyes, and other related toxins. These pollutants affect aquatic organisms and lead to water pollution. NPs can be utilized to remove water contaminants because their small size is paired with a big surface area, and can provide catalytic activity or adsorb organic pollutants [56]. Both Ag and AuNPs have shown to provide sufficient amounts of catalytic activity with respect to the removal of organic dyes [57,58].

6. FUTURE DIRECTIONS IN NANOPARTICLE RESEARCH

Advanced Synthesis Techniques: New progression in the nanoparticle synthesis area is now taking form with the development of new synthesis techniques that provide more control over size, shape, composition, and functionality of nanoparticles. These include bottom-up approaches such as atomic layer deposition, molecular self-assembly, and biologically inspired synthesis methods, as well as top-down approaches such as nanolithography and laser-assisted synthesis techniques.[59]

Multifunctional Nanoparticles: The design and engineering of nanoparticles with diverse functions and specific functionalities is rapidly developing. The future of research will be combining these multiple functions into nanoparticles with loaded modalities, such as therapeutic agents, imaging probes, targeting ligands, and stimuli-responsive components, allowing for synergistic effects and performance improvement in biomedical, environmental, and energy applications.[60]

Precision Medicine: Nanoparticles may provide unique opportunities to facilitate precision medicine paradigms through personalized diagnosis and treatment. Future advances in nanoparticle-based therapeutics include targeted drug delivery systems, theragnostic nanoparticles that enable simultaneous imaging and treatment, and precision nanomedicine platforms that are tailored to individual patient characteristics, disease profiles, and treatment responses.[61]

Nanomaterials for Sustainable Technologies: Nanoparticles are an integral component to the current advancement of sustainable technologies for environmental remediation, renewable energy, and resource conservation. Future research directions should include investigation of nanoparticle-based materials and devices for water purification, air pollution control, energy storage and conversion, and sustainable agriculture, with the consideration of efficiency, cost, and environmental-friendly procedures.

Nanotoxicology and Safety Assessment: While the incorporation of nanoparticles increases in myriad applications, note that the daunting challenges of nanotoxicology and safety assessment will have to be confronted head-on. In terms of future research direction, the following would include expanding nanotoxicology [63] studies

to better understand the mechanisms of nanoparticle toxicity, determination of predictive models of nanoparticle safety, classification systems for risk assessment, and regulatory decision-making.

7. CONCLUSION

Nanotechnology is enhancing our everyday life, by improving the function and performance of everyday items. By providing clean and renewable energy for a sustainable future and safer air and water, it is creating a clean environment. Nanotechnology has attracted a substantial amount of attention, with investment from leading universities, companies, and organizations focused more on developing new products, functions, and applications. There is a lot of research and development occurring in the highly defined science of nanotechnology to turn the concept into practice. It is being developed for a number of new uses to improve performance and efficiency of an object or process, which will decrease cost and be more economically feasible for everyone. With lower costs and being environmentally friendly, the future of nanotechnology is bright.

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