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Biomedical Potential of Nanotechnology: A Review of Emerging Applications and Future Prospects

Pankaj Kumar*, **Kamaljeet Singh, Lakhwinder Singh, Jagmeet Singh and Sahil Gupta**
Department of Physical and Mathematical Science, Baba Farid College, Bathinda, Punjab, India
*Corresponding author's email: pankajkullu22451@gmail.com

Abstract

Nanotechnology is an emerging field that covers a wide range of technologies that are presently under development at the nanoscale. It plays a major role in the development of innovative methods to produce new products, to substitute existing production equipment, and to reformulate new materials and chemicals with improved performance, resulting in less consumption of energy and materials and reduced harm to the environment as well as environmental remediation. The ability to investigate substances at the molecular level has boosted the search for materials with outstanding properties for use in medicine. The application of these novel materials has generated the new research field of nanobiotechnology, which plays a central role in disease diagnosis, drug design and delivery, and implants. In this review, we provide an overview of the use of metallic and metal oxide nanoparticles (MONPs), carbon-nanotubes (CNTs), liposomes, and nanopatterned flat surfaces for specific biomedical applications. The chemical and physical properties of the surface of these materials allow their use in diagnosis, biosensing and bioimaging devices, drug delivery systems, and bone substitute implants. The toxicology of these particles is also discussed in the light of a new field referred to as nanotoxicology that studies the surface effects emerging from nanostructured materials.

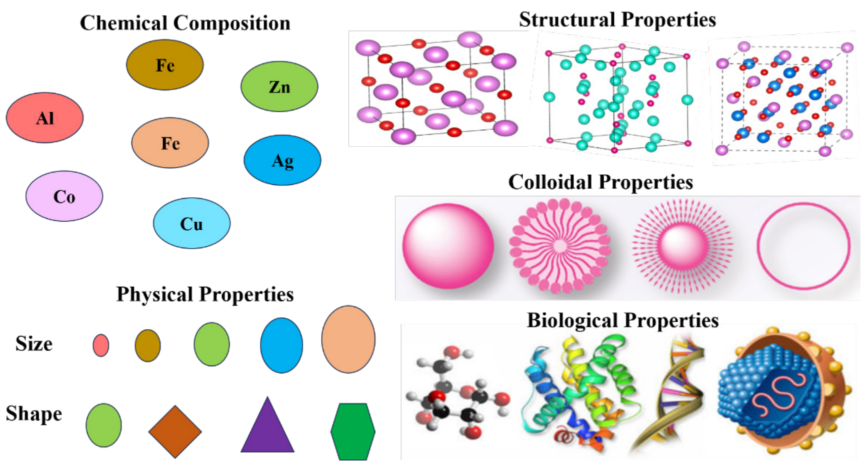
Keywords: Nanobiotechnology; inorganic particles; liposomes; nanopatterned surfaces

Introduction

Nanotechnology plays a significant role in economic growth at all levels through the development of new industries, the enhancement of current materials, and the promotion of innovation in fields like manufacturing, healthcare, and energy. Its ability to boost productivity and open up new opportunities makes it a significant factor affecting the economy's future. Interesting phenomena like mechanical, optical, electrical, magnetic, and a host of other qualities can behave significantly differently in the hybrid that exists between 1 and 100 nm (Ebrahimi et al., 2024). A nanometer is 80,000 times thinner than human hair, or one billionth of a meter. Therefore, sizes larger than a few atoms but smaller than the wavelength of visible light fall inside the nanometer domain. The manipulation of materials that are 100 nm or smaller in at least one dimension is known as nanotechnology.

Figure 1

Altered material properties at the nanoscale and the synergistic effects of combining different materials in Nanotechnology



When, as illustrated in (Fig. 1), the physical, chemical, colloidal, or biological characteristics differ significantly from those of the bulk material (Duman et al., 2024). A wide range of technologies functioning at the nanoscale are included in nanotechnology, a rapidly developing field of study. Its impact on contemporary science and engineering is revolutionary, propelling the development of novel production techniques, the replacement of traditional manufacturing procedures, and the development of new, better-performing materials and chemicals. These developments, which include successful environmental remediation techniques, help to minimize environmental impact, increase material efficiency, and lower energy consumption. The discovery of materials with exceptional qualities appropriate for clinical applications has been sped up in the biomedical field by the capacity to manipulate and study substances at the molecular level. As a result, the dynamic interdisciplinary field of nanobiotechnology has emerged, which is essential to regenerative therapies, drug design and delivery, and disease diagnosis (Kumar, Kumar & Thakur, 2023). Nanocomposites are classified according to the dimensionality of the nanofiller. It is possible to envision systems that are zero-dimensional nanoparticles, one-dimensional (nanofibers), two-dimensional (nanolayers), and three-dimensional (Ain et al., 2024). Lamellar nanocomposites also come in two varieties: interspersed and eliminated. The number of polymer layers in the interlamellar space is predetermined in intercalated nanocomposites, and the polymer chains alternate with the inorganic layers in a predetermined compositional ratio.

The number of polymer chains separating the layers in exfoliated nanocomposites varies practically continuously, and the layers are more than 100 Å apart. It will be possible to create new materials and products by figuring out and changing the structure of materials and their interfaces at the atomic and nanoscales. In the upcoming decades, wood and wood-based materials will have a significant opportunity to enhance their performance and usefulness, create new product generations, and enter new market segments thanks to nanotechnology (Kumar et al., 2023a). The question of why nanotechnology matters can now be asked. a) Faster, less material, less energy, less area. b) new phenomena and characteristics. b) The most effective production length scale. d) Living/non-living intersection. Materials with one or more dimensions on the nanoscale (less than 100 nm) are incorporated into a polymer matrix to create polymer nanocomposites. Nanofillers, NPs, nanoscale building blocks, and nonreinforcements are some of the names given to these nanomaterials in the literature (Santulli et al., 2024; Kumar et al., 2023b). Nanocomposites, a type of polymer, are more stiff, strong, tough, thermally stable, barrier-like, and flame-retardant than a pure polymer matrix. These composites' large surface area gives them unique properties that can be changed to produce materials with various biological traits and uses. Nanotechnology-based products are increasingly useful in biomedicine, particularly in the fields of prosthetics, implants, drug delivery, and diagnosis (Haleem et al., 2023; Kumar & Kumar, 2024). CNTs, liposomes, metallic surfaces, and inorganic and metal NPs are common components found in nanotechnology goods. The precise use of nanomaterials is determined by surface chemistry, surface physics, surface thermodynamics, and toxicological consequences (Bhatia et al., 2025).

One method for achieving better responses targeted at a particular application is the design of nanostructures by manipulating their surface features. Here, we concentrate on the applications of inorganic (metal and metal oxide) and organic (carbon nanotubes and liposomes) NPs and nanopatterned flat surfaces in drug delivery systems, bone-replacing implants, biosensing and bioimaging devices, and diagnosis. A new subject called nanotoxicology, which examines the surface effects resulting from nanostructured materials, is also studied concerning the toxicology of tiny particles. This review emphasizes that nanotechnology has the potential to transform biomedical applications by creating intelligent, individualized, and targeted healthcare solutions. Prospects for the future include the development of sophisticated nanosensors for early disease detection, responsive nanocarriers for precise drug delivery, and nanostructured scaffolds for tissue regeneration. Furthermore, a revolutionary path for healthcare is represented by the incorporation of nanotechnology into immunotherapy, regenerative medicine, and minimally invasive procedures. This overview is novel because it takes a forward-looking stance, highlighting both the expected innovations that have the potential to revolutionize clinical practices as well as the applications that are currently in use. This work provides a thorough roadmap for the future translation of nanotechnology from research to practical biomedical solutions by critically addressing the issues of biocompatibility, scalability, and regulatory barriers.

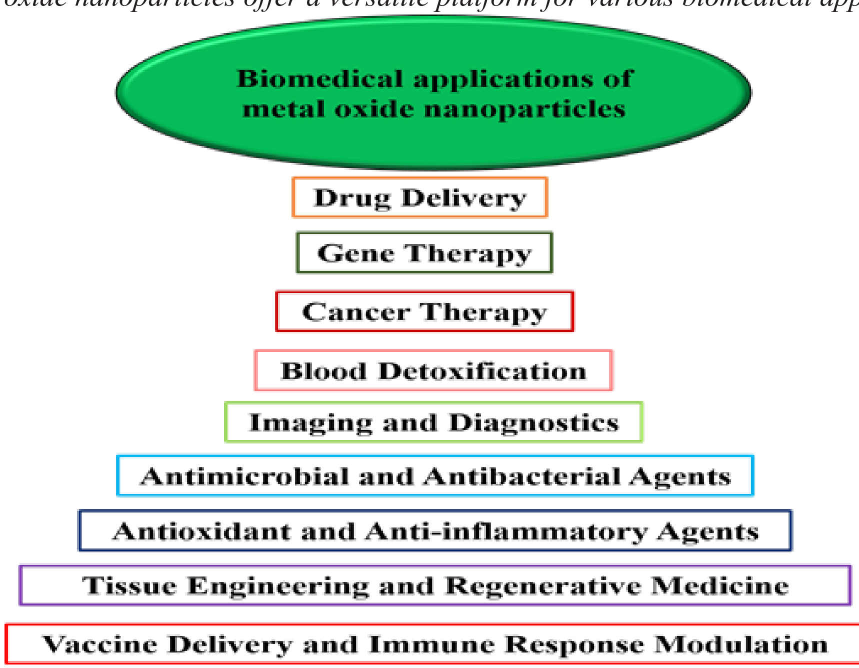
Results

Biomedical Applications of Metal Oxide Nanoparticles (MONPs)

MONPs are highly valued in the biomedical field due to their unique characteristics and versatility, as shown in Fig. 2 and Table 1.

Figure 2

Metal oxide nanoparticles offer a versatile platform for various biomedical applications

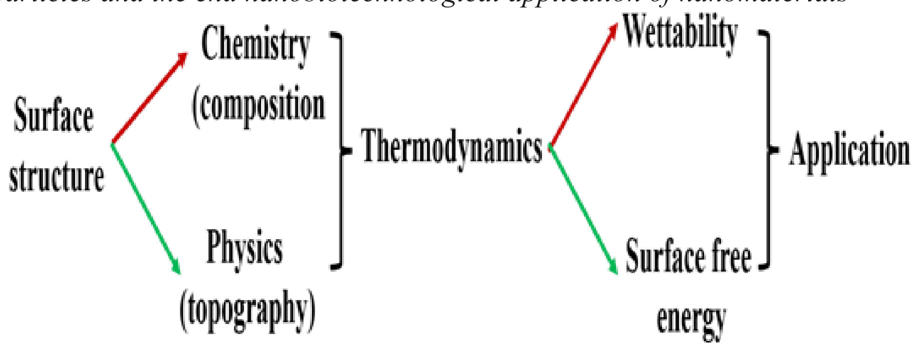


Through the use of photothermal, photodynamic, and magnetic hyperthermia treatments, they improve imaging as MRI contrast agents, facilitate targeted, controlled release of drugs, and aid in cancer treatments (Kimta et al., 2024). Additionally, MONPs stimulate tissue engineering, which promotes bone and nerve regeneration, and provide antibacterial qualities for infection management. They can be used to treat oxidative stress-related disorders because of their anti-inflammatory and antioxidant properties. MONPs have shown promise in a variety of medical applications and are also being investigated for blood detoxification, gene therapy, and as adjuvants in vaccines.

Numerous medical gadgets have been built using MONPs. Photoacoustic imaging, magnetic particle hyperthermia (Thakur et al., 2024), contrast agents for magnetic resonance imaging, magnetic particle imaging, and ultrasonic techniques are just a few of the therapeutic and diagnostic applications for iron oxide's magnetic properties. Zinc oxide's (ZnO) electrical structure is helpful for medicinal applications; for instance, ZnO nanowires inherent fluorescence has been used to image cancer cells (Gupta, Hassan, & Barick, 2023). To achieve this, ZnO nanowires' surface functionalization improves their water solubility, biocompatibility, and cellular toxicity. Photosensitive biosensors are produced by functionalizing the ZnO surface with certain biomolecules. The rapid adsorption of plasma proteins is facilitated by the increased surface area of NPs (Sytu, & Hahm, 2024). Therefore, the physical topography and chemical makeup of NPs surfaces, along with the combination of these characteristics (wettability and surface-free energy), determine how the particles interact with other substances and determine their final use (Fig. 3).

Figure 3

Correlation between the main chemical and physical properties of the surface of nanoparticles and the end nanobiotechnological application of nanomaterials



Numerous biological uses exist for titanium oxide (TiO_2). For example, the biofluid initially comes into touch with a thin layer of TiO_2 that forms spontaneously on the upper surface of metallic titanium in bone-substituting materials (Shabib Akhtar et al., 2024). Zirconium oxide is compatible with the same kind of hard tissues as titanium, it has lately been used for dental implants (Nikkerdar et al., 2024). Metal NPs are useful for creating molecular contrast because of their significant optical absorption associated with noble metals' surface plasmon resonance. The use of materials containing metal NPs in the sensing and diagnostic domains has been prompted by absorption and scattering in the visible and near-infrared spectra. To improve luminescence, gold NPs can be added to the formulation of substrates or coated on suitable substrates. The size and shape of the particles, which dictate their absorption and scattering characteristics, affect how this technology is applied. Photoacoustic imaging has been utilized to track blood flow in vivo using gold nanorods, which absorb in the near-infrared (Li et al., 2024). Examples of applications utilizing gold nanocages, nanoshells, and nanospheres can be found in the literature. Due to their strong chemical affinity, sulfur- containing chemicals can be used to alter the surface of gold NPs. Gold NPs' ability to bind to particular tissues is improved when they are modified with biospecific chemicals (Hossain et al., 2024). In vitro, for instance, surface-labeled gold nanoshells have been utilized to target cancer cells, with optical microscopy confirming the results.

Table 1

Different metal oxide nanoparticles provide an adaptable platform for a range of biomedical applications

Nanoparticle Type	Biomedical Applications	Mechanism	Examples	References
Au NPs	Cancer therapy, drug delivery, imaging	Photothermal therapy, targeted drug delivery	Imaging for tumor localization	(Ghafari, Asefnejad, & Ogbemudia, 2024)
Ag-NPs	Antibacterial agents, wound healing	Reactive oxygen species generation, cell membrane damage	Antibacterial coatings on dressings	(Jangid et al., 2024)
Fe NPs	Magnetic resonance imaging (MRI), targeted drug delivery, and hyperthermia treatment	Magnetic properties, heat induction	MRI contrast agents, tumor targeting	(Kumar et al., 2024a)

Silica NPs	Drug delivery, gene delivery, biosensors	High surface area, porous structure	Gene therapy for genetic disease	(Behyar et al., 2024)
Lipid-based NPs	Vaccine delivery, gene therapy, targeted drug delivery	Lipophilic properties, fusion with cell membranes	mRNA vaccines	(Kumar et al., 2025)
Quantum Dots	Bioimaging, cancer diagnostics	Fluorescent properties, high brightness	Tumor markers, cell tracking	(Kunachowicz, et al., 2024)
Polymeric NPs	Controlled drug release, vaccine delivery	Biodegradable matrix, pH- sensitive drug release	Sustained cancer therapy	(Sharma & Kumar, 2021)
Carbon-based NPs	Drug delivery, imaging, tissue engineering	High surface area, strong mechanical properties	Carbon nanotubes for tissue Scaffolding	(Parvin et al., 2024)
CeO NPs	Antioxidant therapy, anti-inflammatory applications	Scavenging of reactive oxygen species	Treatment for neurodegenerative diseases	(Choudary et al., 2024)

Carbon Nanotubes

Carbon nanotubes (CNTs) physical and chemical characteristics have inspired their use in several scientific fields. Their application in nanobiotechnology has expanded due to surface modification and molecular functionalization with biological molecules. These altered particles offer evenly distributed samples that are appropriate for physiological settings. Table 2 lists the main biomedical uses for carbon nanotubes. Because of their ability to travel freely within the body due to their nanoscale size, nanotubes may be helpful drug delivery vehicles in this situation. The bioavailability of methotrexate, a drug used in cancer therapy, significantly increases when it is immobilized on the surface of a double-functionalized carbon nanotube, enhancing its therapeutic effectiveness (Maghimaa et al., 2024). To target and change cell activity at the subcellular or molecular level, the active ingredient can either be added to the tube or bound to the particle's surface. Additionally, a variety of cells can absorb biofunctionalized single- or multi-walled CNTs, and they can pass through various cellular barriers and interact with DNA (Sonowal & Gautam, 2024). Additionally, cells can absorb and interact with cationic CNTs complexed with plasmid DNA. CNTs are appropriate scaffolds for bone regeneration and osteoblast proliferation. We have shown that unaltered single- and multi-walled CNTs can be employed safely in osteoblast cells at concentrations of up to 10-2 mg/mL, and that their toxicity varies with concentration (Mamidi et al., 2025). As a new generation of tubular structures for bone regeneration, we recently suggested using collagen-modified calcium carbonate nanotubes.

Table 2

Biomedical applications of CNTs and their uses

Biomedical Application	Details	References
Biosensing	CNTs are used in electrochemical biosensors for detecting biomarkers due to their high conductivity and surface functionality.	(Li et al., 2024)
Drug Delivery	Functionalized CNTs enable targeted drug delivery by encapsulating therapeutic agents, enhancing their uptake by specific cells.	(Khan et al., 2024)
Cancer Therapy	CNTs are utilized in cancer diagnosis and targeted therapy, either for direct drug delivery or as carriers for photothermal therapy.	(Maghimaa et al., 2024)
Regenerative Medicine	CNTs serve as scaffolds in tissue engineering, promoting cell proliferation and differentiation due to their conductivity.	(Parvin et al., 2024)
Antibacterial Therapy	CNTs, functionalized with antibacterial agents, are used for treating infections by enhancing microbial inhibition.	(Jonathan, & Agbini, 2024)
Biomedical Imaging	CNTs are employed in bioimaging as contrast agents for enhanced visibility in diagnostic imaging.	(Aher et al., 2024)

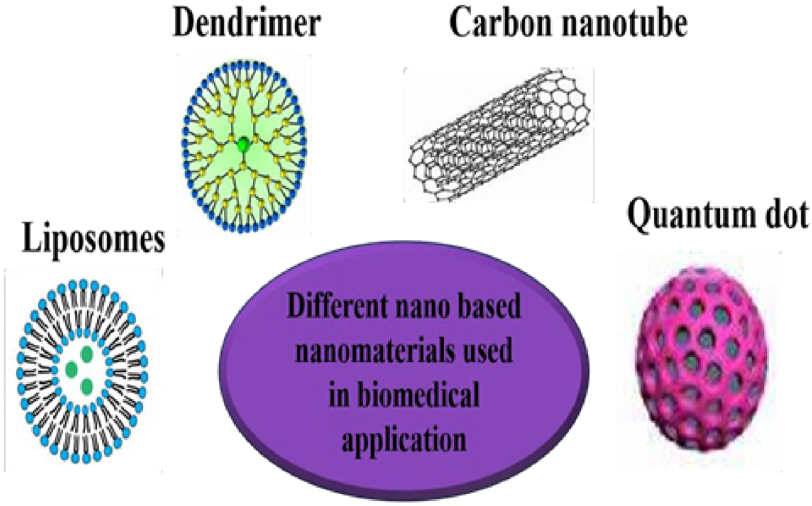
Neurodegenerative Disease	CNTs are investigated for drug delivery systems targeting Alzheimer's disease due to their ability to cross the blood-brain barrier.	(Al-zharani et al., 2024)
Wound Healing	CNT-based materials accelerate wound healing by promoting cell growth and tissue regeneration.	(Elabbasy et al., 2024)
Diagnostics	CNTs enable precise diagnostics through advanced biosensing platforms that detect diseases at an early stage.	(Acharya et al., 2024)
Gene Therapy	CNTs facilitate gene delivery by assisting in the transport of genetic material into cells with minimal toxicity.	(Yazdani et al., 2024)

Liposomes and Nanobiotechnology

Small synthetic lipid-bilayer spherical vesicles known as liposomes were initially described by Bangham and Horne. Drug delivery, gene therapy, and nanobiotechnology applications can all benefit greatly from the use of liposomes, a form of nanoparticle made of lipid bilayers that encapsulate a variety of compounds (Kumar, 2024). Targeting and regulating the release of therapeutic medicines is made much easier by their capacity to encapsulate both hydrophilic and hydrophobic compounds. As illustrated in Fig. 4, liposomes are employed in nanobiotechnology to transport medications straight to target cells or tissues, reducing adverse effects and enhancing therapeutic efficacy. By adjusting their size, content, and surface charge, liposomes with various characteristics can be produced. By selecting particular lipids, the bilayer's stiffness and fluidity can also be adjusted (Mitsuhashi et al., 2023). The diameter of these artificial membrane models can be used to categorize them. Large unilamellar vesicles (LUVs) are between 200 and 1000 nm in size, while small unilamellar vesicles are between 20 and 100 nm. The vesicles have an interior aqueous cavity and a single lipid bilayer. The number of lipid bilayers in liposomes can also be used to categorize them. Multilamellar vesicles, which have sizes between 400 and 3500 nm, are made up of several concentric phospholipid bilayers intercalated with aqueous compartments (Sulthana, Shrestha, & Aryal, 2024). Liposomes have been used extensively over the past 20 years for a variety of purposes, including gene therapy, vaccinations, and medication delivery for cancer. A variety of bioactive substances, including anagenic proteins, antioxidants, and antimicrobials, can be delivered via these vesicles. Once these compounds are encapsulated, their functioning is maintained. Furthermore, substances with varying degrees of solubility may be encapsulated at the surface of lipid bilayers or within the aqueous cavity (Bakhshizadeh et al., 2024). Liposomes might be expected to deliver medications with a low disintegration rate and fewer side effects because they are non-immunogenic, potentially nontoxic, and degradable under physiological settings (Li et al., 2024).

Figure 4

Lipid-based nanoparticles for the treatment of biomedical applications



Nanotechnology in Diagnostics

Diagnostics benefits greatly from nanotechnology, especially in imaging applications like optical imaging and magnetic resonance imaging (MRI), where nanoparticles (NPs) are proven diagnostic instruments. Because they are 100 times more brilliant than organic dyes, semiconductor nanocrystals called quantum dots (QDs) are widely utilized in optical imaging (Palanisamy et al., 2024). To illuminate cells in deep tissues, the number of NPs in the cytoplasm of the cell is crucial. QDs have disadvantages even if they work well as tagging materials. To obtain adequate brightness, a greater number of QDs is needed, which presents possible toxicity issues (Kumar et al., 2024b). Furthermore, tracking biomolecules labeled with QDs may become more difficult due to their blinking habit. As a result, creating fluorescent nanoparticles for in vivo imaging remains a difficulty. Because silicon nanocrystals are harmless to cells and do not need a thick surface covering to shield the nanocrystal core from the environment, they are more attractive than QDs (Kumar et al., 2024c).

Nanotechnology in Therapeutics

The generated heat is efficiently transferred to the surrounding tissues by metallic nanoparticles (NPs), which are renowned for their exceptional thermal conductivity (Thakur et al., 2022). Because of their propensity to accumulate in tumors when given intravenously, they are useful in therapeutic applications. The materials include gold (Au) NPs, carbon nanotubes (CNTs), and magnetic nanoparticles (e.g., Fe_2O_3 NPs (Kumar et al., 2025b), superparamagnetic Fe_2O_3 NPs (Kumar, Pathak & Thakur, 2024), and doped

Fe_2O_3 NPs (Thakur & Kumar, 2024). An alternating magnetic field activates magnetic nanoparticles (NPs), which generate heat and target tumor cells while avoiding damage to healthy tissues. Superparamagnetic Fe_2O_3 nanoparticles (NPs) have a high localization in malignancies and are particularly efficient as heat producers (Kumar et al., 2024d). Doped FeO_3 NPs increase the rate of selective absorption and heat generation in a magnetic field. Furthermore, electrospun fibers with NPs are becoming more popular for postoperative care; superparamagnetic FeO_3, graphene oxide, and doxorubicin-incorporated nanofibers have demonstrated effectiveness in encouraging tissue regeneration and avoiding the recurrence of breast cancer (Kumar et al., 2024e). Photothermal activation is how Au NPs work, in contrast to magnetic NPs.

Drug Delivery

Lipids are readily available, inexpensive, biodegradable, biocompatible, inert, non-toxic, and non-immunogenic, they are frequently employed as carriers for antiviral medications. They are especially useful in drug delivery systems because of their special qualities, which include better drug performance, controlled release, improved interface interactions, tiny size, vast surface area, and high drug-loading capacity. Many disorders are linked to mRNA processing and translation that can be inhibited by antisense oligonucleotide (ASO) medications (Jawale et al., 2024). ASO treatments, however, have drawbacks, including poor cellular absorption, short circulation half-life, and limited biological stability when given freely. ASO cellular absorption is greatly enhanced by nanoparticles (NPs) composed of human serum albumin (HSA) cross-linked with glutaraldehyde and ASO. The presence of drug-loaded NPs in a variety of cell types, such as lung cancer cells (A549) and breast cancer cells (MDA-MB-468, MCF-7, and BT-474), is confirmed by confocal laser scanning microscope pictures (Figure 3). After 24 hours, NPs were detectable at an incubation temperature of 37°C (body temperature), with MDA-MB-468 and MCF-7 cells showing the fastest absorption.

Gene Therapy

The goal of gene therapy is to replace or repair disease-causing genes by introducing healthy genes into target cells. Although viral vectors are frequently used to transfer these genes, there are risks associated with them, such as the possibility of cell injury since inflectionless NPs attached to DNA have demonstrated promise in transferring genes to stem cells. Recently, surface-modified gold (Au) NPs carrying DNA have been shown to help with photoacoustic imaging by combining the effects of gene therapy and photothermal therapy (Alzahrani et al., 2023). Introducing new genes into diseased cells or surrounding tissues to cause cell death, stop the spread of cancer, or fix genetic defects to restore normal cell function is known as gene transfer, and it is a new method of treating cancer. In one technique, known as gene-directed enzyme prodrug therapy, a gene for an enzyme that is not native to the malignant tissue is directed there, where it activates a prodrug that is later delivered. Insights into nuclease activity and the development of safe and effective gene delivery vectors will help genome editing become a viable cancer treatment option in the future (Song et al., 2024).

Nanotechnology to Engineer the Surface of Metallic Implants

Applications of nanotechnology can also be seen in implants and tissue engineering. Better biological responses from osteogenic cells and efficient mechanical contact between tissue and implant should result from the material's ability to increase surface area and adjust surface roughness at the nanometric scale. The most appealing materials for bone replacement applications are thought to be titanium and its alloys. This metal is widely used because of its better mechanical qualities, good corrosion resistance, minimal surface reactivity, and acceptable in vitro and in vivo biocompatibility. Despite the possibility of a thin fibrous layer separating the metallic implant from the bone, which indicates a failure in the osteointegration process, the live tissue heals in close proximity to the metal. To accomplish good osteointegration and strengthen the bone implant interface in this situation, the implant's surface must be modified (Ramezani et al., 2023), altering the surface should initially simply alter the topography. Nevertheless, the incorporation of bioactive substances and the production of nanoscale roughness seem to be more promising approaches for biomedical uses. We go over which aspects of implant surfaces need to be changed in the ensuing subsections in order to improve host tissue responses. We also explain the application of nanotechnology to nanometer-scale implant surface engineering. In bone replacement applications, altering metallic surfaces enhances the interaction between implants and living tissue. The effective development of bone tissue at the implant's surface is necessary for successful orthopedic implant osteointegration (Bandyopadhyay et al., 2023). To optimize implant anchoring to the tissue, surface engineering modifies characteristics such as topography, wettability, charge, and chemical composition. According to clinical studies, the rate of bone formation increases as one moves away from the implant surface as opposed to toward it.

Bio-inspired Modifications of Surfaces

One of the most popular methods for altering the metallic surfaces of implants is the inclusion of bioactive minerals that are modeled after the structure of bone. Because it predefines nanochemical and/or nanophysical structures, biomimetics is a desired tactic. In biomaterials science, calcium phosphate (CaP)-based coatings are frequently manufactured, and their application to implants has a major impact on the process of bone regeneration (Zhang, Wang & Guo, 2024). Nevertheless, these techniques are intricate and necessitate costly equipment and extremely high temperatures. Although this technique can necessitate extended exposure periods, it enables the creation of continuous

CaP coatings with regulated surface topography (Furko, Balázsi & Balázsi, 2023). One of the most widely utilized physiological solutions is simulated body fluid (SBF). A common technique used to assess a material's bioactivity is SBF, which is made up of a supersaturated CaP solution that mimics the pH and ionic makeup of bodily fluids.

Toxicology of Nanomaterials

Although nanoparticles have shown promise in biomedical applications, little is known about their toxicological effects. Numerous factors, such as dosage and content, as well as physicochemical characteristics including size, surface charge, roughness, crystalline structure, and shape, influence how poisonous nanomaterials are. The dimensions of materials affect their physicochemical characteristics. As a result, nano specific toxic events are induced by the toxicological behavior of the bulk substance. To better comprehend the physicochemical characteristics of nanoparticles and their harmful impacts, the term "nanotoxicology" has been employed. Cell culture studies are the basis of the majority of nanotoxicological research (Verma et al., 2023). A number of studies have used proteins in vitro and basic biomimetic cell membrane models, such as Langmuir monolayers. However, in order to predict how nanomaterials will interact with biological systems, verification in vivo experiments, as results from in vitro tests may not reflect their in vivo effects. Despite the fact that several assays have been performed, inconsistent methodology has resulted in incorrect toxicological findings. The toxicological effects of nanomaterials, for instance, do not align with the traditional toxicological approach, which looks at exposure duration and dosage. Careful consideration must be given to the choice of appropriate dose measurements.

Future of Nanomedicine

The fields of drug delivery and nanomedicine are expanding quickly, with several clinical trials and 1500 patents. Nonmedical technology has greatly aided in the diagnosis and treatment of diseases like cancer. Without altering the normal physiology of the cells, nanoparticles can be utilized to deliver precise dosages of medications to diseased cells, including cancer cells. The size of the nanoparticles varies, though, and further study is required to guarantee consistent consistency as well as the ability to load and release drugs. Nanoparticles made of metals, such gold and silver, have demonstrated promise for use in diagnostic procedures like radiation-based heat therapy for targeted removal. Because nanomedicine is still in its infancy and many important aspects are still unknown, its actual impact on healthcare is still limited, despite its potential. Understanding illness molecular markers and creating theoretical mathematical models for controlled drug release, technological evaluation, and therapeutic effects should be the main goals of future study. With an emphasis on more sophisticated and interdisciplinary methods, the future of drug delivery technology and nanomedicine is bright.

Discussion

Biomedical applications have been transformed by nanotechnology, which provides novel approaches to tissue engineering, drug delivery, diagnostics, and regenerative medicine. With a particular focus on metallic and metal oxide nanoparticles (MONPs), carbon nanotubes (CNTs), liposomes, and nanopatterned surfaces, this review examines the growing biomedical potential of nanotechnology. Future prospects and advancements in the field are highlighted. The study assesses nanotechnology's present status, uses, and revolutionary potential in contemporary healthcare. Because of their distinct physicochemical characteristics, nanomaterials can precisely interact with biological systems. These characteristics have been crucial in the creation of cutting-edge biomedical instruments like bioengineered implants, targeted drug delivery systems, and nanoscale imaging equipment. Among the different nanomaterials, liposomes have been acknowledged for their potential to improve the bioavailability of therapeutic agents, while MONPs and CNTs have demonstrated notable promise in drug encapsulation and controlled release. By encouraging cellular growth and differentiation, nanopatterned surfaces are advancing tissue engineering and opening up new avenues for regenerative medicine. Precision medicine, in which patient-specific treatments are developed to improve therapeutic results, is made possible by the incorporation of nanotechnology into biomedical systems. Nanocarriers provide highly targeted drug delivery, reducing side effects and improving treatment efficacy because they can react to physiological stimuli. Additionally, nanotechnology-powered advanced biosensing and bioimaging platforms have made it possible to detect diseases like cancer earlier, which is crucial for treatment planning. Another field where nanotechnology has great promise is regenerative medicine, specifically in the creation of scaffolds and materials that promote tissue repair and regeneration. Concerns about nanomaterials' biocompatibility, possible toxicity, and long-term impacts on humans are still significant. Understanding how nanomaterials interact with biological systems has advanced significantly in the young field of nanotoxicology, which has also yielded important insights into the safety profiles of these materials. To ensure the safe and efficient use of nanomaterials in clinical settings, more research is required to develop standardized procedures for evaluating their toxicity and safety. Looking ahead, the creation of multifunctional nanomaterials like theranostic agents that can be used for both diagnosis and treatment at the same time represents the future of biomedical nanotechnology. The use of nanotechnology in personalized medicine, such as the development of nanoscale drug delivery systems and the deployment of nano-robots for minimally invasive surgery, has the potential to completely transform the way complex diseases are treated. Furthermore, it is anticipated that advancements in nanotechnology will be crucial in the creation of immune treatments, diagnostic instruments, and next-generation vaccines. In conclusion, even though the use of nanotechnology in biomedicine has advanced significantly, its full potential is still untapped. Future developments in the design of nanomaterials and a better comprehension of their biological interactions will influence the next wave of medical interventions, resulting in safer, more effective, and more individualized healthcare solutions.

Conclusion

Nanotechnology has revolutionized the biomedical field, enabling significant advancements in disease diagnosis, drug delivery, and therapeutic treatments. Novel substances like metal oxide nanoparticles, carbon nanotubes, and liposomes have been created as a result of the capacity to modify materials at the nanoscale. These substances have a wide range of medical applications. A controlled, focused release of hydrophobic and hydrophilic molecules is ensured by liposomes, while metal oxide nanoparticles, carbon nanotubes, and liposomes are utilized in targeted medication delivery, cancer therapy, and imaging because of their special qualities. Although they create difficulties in nanotoxicology, nanopatterned surfaces have potential uses in biosensing and bioimaging. To increase the biocompatibility and effectiveness of nanomaterials in medical applications, research into surface alterations and bio-inspired tactics is essential. To sum up, nanobiotechnology is a game-changer in the medical field, providing novel approaches to tissue engineering, medication delivery, and diagnostics. The application of nanotechnology in clinical settings has the potential to enhance patient outcomes as research progresses, but optimizing its advantages will require ongoing focus on safety and ethical issues.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Conflict of Interest Statement

There is no conflict of interest between the authors as all played their specific role.

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