Chapter 50

Nano Particles in the Battle against Disease

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ABSTRACT

Nanoparticles have revolutionized the field of medicine with their diverse applications in disease treatment and diagnosis. This study explains different kinds of nanoparticles and how they can be used to fight against diseases. These include organic nanoparticles, polymer nanoparticles, liposomes, micelles, dendrimers, and metal-based nanoparticles like iron, gold, and silver. Organic nanoparticles and polymer nanoparticles are valuable for drug delivery due to their ability to encapsulate and release therapeutic agents in a controlled manner. Liposomes and micelles enhance drug solubility and stability, improving the efficacy of treatments. Due to their highly branched structures, dendrimers provide therapeutic applications with multi-functionality and precise targeting. Silver, gold, and iron nanoparticles are among the special qualities of metal nanoparticles that include targeted therapy, improved imaging, and antibacterial activity. Collectively, these advanced nanoparticles provide new and promising ways to treat a wide range of diseases more effectively and personalized, expanding the possibilities of modern medicine.

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INTRODUCTION

Tiny bits of stuff ranging from one to a hundred nanometers are called ultrafine or nanoparticles. This term can also include really small fibers and tubes in just two directions, or bigger particles up to 500 nm (Suhag et al., (2023). At the smallest scale, metal particles smaller than one nanometer are usually called atom clusters. This study highlights the importance of understanding nanotechnology because it has the potential to be super useful in many areas. Nanotechnology has already made big improvements in things like transportation, security, farming, healthcare, electronics, and more. It's basically making a positive impact on various aspects of technology and the economy. Nanotechnology is a mix of different fields like chemistry, engineering, materials science, and biotechnology. It uses these to make cool materials with special features, all based on their super tiny size. This book explores how nanotechnology has been used a lot recently, and its influence on big tech advances makes it a really groundbreaking science. Nanotechnology is like a problem-solving superhero because it's expected to help fix many issues we have. It does a bunch of things, like making tiny materials and trying to control stuff right at the tiniest level. It even messes around with the physics of things we already use and comes up with new ways to build stuff using molecular self-assembly. Tiny particles called NMs are like important players in today's medicine. They help deliver medicine and genes to tumors and are good for imaging too. Sometimes, they can even do studies and treatments that we couldn't do otherwise. But, they bring challenges for society and the environment, especially in terms of being harmful. So, we need to carefully check how we use them in medicine. Understanding how these tiny particles affect diseases can also help us come up with better ways to diagnose, treat, and prevent illnesses (Malik et al., 2023).

This review highlights how tiny particles (NPs) have been super helpful in today's medicine and delivering medications. It also tries to guess how nanotechnology (NT) will change things. In a newer field called pharmaceutical nanotechnology, there are cool tools and opportunities that might really help with diagnosing and treating illnesses. Recently, medicines based on tiny particles have shown a lot of potential for delivering drugs where needed and for bioactive and diagnostic purposes. Nanotechnology is pretty clever because it gives us special materials for building body tissues. In the field of nano-engineered drugs, we use smart tools for predicting, treating, and delivering medications. There are already some products and ways of delivering drugs based on nanotechnology. In pharmaceutical nanotechnology, we use tiny technology to make products better by changing them in various ways as shown in Figure 1. Medicines with these tiny changes have special features like staying in the body longer, going to the right place, and working better (Joseph et al., 2023).

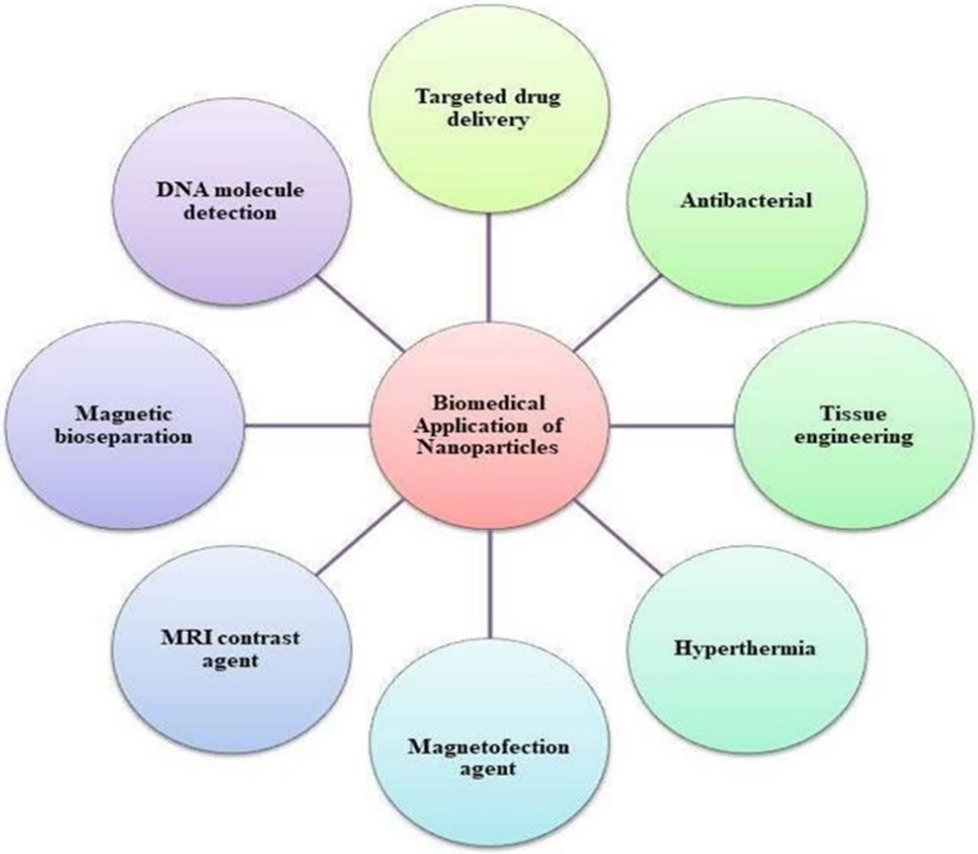

Fig. 1: (Flowchart of uses of Nanoparticles)

Tiny medicines, also called nano-pharmaceuticals, have changed the way we give and get drugs in medicine. These include things like tiny particles made of different materials. They have the power to prevent illnesses and help us understand diseases better. But, there are some new health risk details that make it tricky to use them in medicines. Scientists are working hard to find solutions for problems like safety issues, ethical concerns, and other challenges in using these tiny medicines.

Hasan, (2015) explained that Scientists today still don't have enough info and advice on using tiny materials and technologies safely. So, when it comes to using nanotechnology in medicine, we're still in the early stages. This chapter gathers what we currently know about tiny particles and the risks they might pose to health, along with the types of tiny medicines that are most commonly used. Nanotechnology involves making and using materials that are super tiny, up to 100 nm in size. It looks into how things behave at really tiny levels, which can help improve tools and processes in biotechnology and medicine, making them cheaper, easier to carry, safe, and simple to use. Tiny particles, called nanoparticles, are used for many things like labeling in labs, treating certain cancers, making optical devices, and even in everyday stuff like clothes and makeup. They're pretty interesting because they resist damage, conduct heat well, and fight against germs. We can make these tiny particles either through chemicals or by using living things. Different types of metallic nanoparticles, like gold and silver, have big uses in industries. This overview aims to talk about these tiny particles, focusing on the types and how they're made.

Organic Nano Particles

Tiny organic particles, like liposomes, polymeric nanoparticles, micelles, and dendrimers, are quite fascinating for many medical uses, such as treating cancer and transporting drugs. Scientists have put in a lot of effort to create these particles with special shapes and features. This review will quickly cover the things used to make these tiny particles and the forces involved. We'll talk about different ways of making them, like self-assembly and microemulsion. After discussing some techniques to change their surfaces, we'll share a vision for better ways to make these tiny particles in the future. We believe people studying medicines, materials, biology, and chemistry will find these topics interesting (Begines et al., 2020).

Polymeric Nanoparticles

New advancements in medicine are revolutionizing theranostics (therapy and diagnosis) through the use of newly developed radiolabeled nanosystems. These nanosystems include polymeric nanoparticles, carbon nanotubes, silica nanoparticles, dendrimers, liposomal carriers, magnetic iron oxide nanoparticles, and inorganic metal-based nanoformulations. Among these, polymeric nanoparticles are gaining attention in the biomedical field due to their favorable characteristics, such as biodegradability, low toxicity, efficient absorption, low surface to mass ratio, and ability to transport other molecules.Polymeric nanoparticles can be attached to radioactive substances, enabling them to carry significant doses of radionuclides for diagnostic, therapeutic, and testing purposes. There are two methods for labeling these nanoparticles: direct labeling and indirect labeling. The choice between these methods depends on the desired qualities of the nanoparticles. One advantage of radionuclide treatment is its ability to spare healthy surrounding tissues while delivering a concentrated dose to the targeted area.In simpler terms, radioactive polymeric nanoparticles show promise in treating and diagnosing various medical conditions, including infectious diseases like tuberculosis, cardiovascular ailments such as cardiac ischemia, and different types of cancer cells or tumors (Wu et al., 2020).

Polymers, which are made up of repeating units called monomers, play a crucial role in drug administration. Polymer nanoparticles come in various forms like nanoshells, polyplexes, nanospheres, and polymersomes, offering a wide range of chemical (biocompatibility, hydrophobicity) and physical (modulus, responsiveness, tunability) characteristics. These polymers can be customized for specific applications by choosing the right monomer, production method, and synthesis approach.In the field of nanomedicine, polymers are versatile and have been employed in vaccine carriers, cancer treatments, pulmonary medication, cardiovascular delivery, antibiotics, and immunological engineering. The flexibility of polymers allows them to be tailored for different medical purposes (Jarai et al., 2020).

Liposomes

A big challenge in treating neurodegenerative diseases is getting medications into the brain because of the blood-brain barrier (BBB). We are particularly concerned with advances in drug delivery systems using liposomes to enhance drugs' crossing of the BBB to treat brain illnesses. We focused on Parkinson's and Alzheimer's diseases as examples of frequent chronic neurodegenerative affections (Seo et al., 2021).

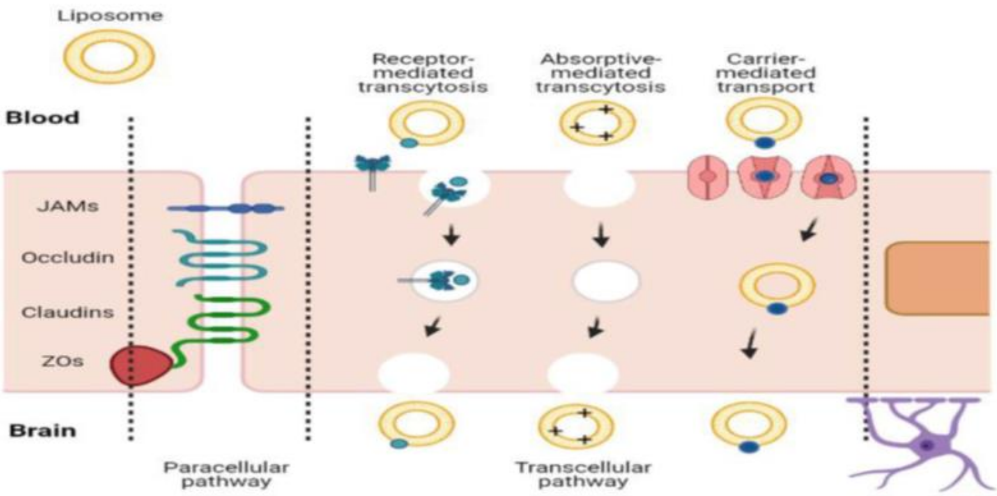

Fig. 2: Drug transport mechanism of liposomes in BBB (Seo, and Park, 2021).

For the improvement of these drugs for these diseases various liposomes with modified surfaces have been prepared including BBB targeting agents (Figure 2). These altered liposomes can cross the blood-brain barrier by a process known as transcytosis. Melting development in liposome engineering offer solutions that enhance the way drug is administered making treatments better. Having the knowledge of the alteration of conditions in the barriers at the body's physiology level is important when need be to advance the penetration of liposome.

Micelles

Amphiphilic copolymers are discussed as a new class of block copolymers which have received much attention from the scientific community over the past few years as suitable materials for forming polymeric micelles with selective abilities of delivering medicines, proteins, peptides, and genes to the brain. It is for these copolymers that can be described by the following peculiarities: their very small size, the charge switching feature, the ability to all stimulus-triggered cargo release, the fact that they have a flexible structure and are capable of self-assemblying. These characteristics help in the avoidance of the problems inherent in the traditional drug formulations for the management of neurological disorders, such as instability, poor penetration into the brain, rapid dissolution and clearance from the brain. The copolymers have better penetration and retention and are easily tunable and, therefore, suitable for diagnosing various brain diseases. This article discusses other modification of micelles including the inclusion of stimuli-sensitive regions on the copolymers; use of smart linkers between cargo molecules that respond to stimuli; and attaching intercalating agents and imaging moieties for the brain targeting and imaging. Details of how polymeric micelles are vital in delivering neurotherapeutics to the brain is also included in the paper. Some of the patents related to polymeric micelles for brain delivery are also described here for the sake of completeness (Kaur et al., 2022).

Dendrimers

Dendrimers as a group of macromolecules that possess certain aspects of long polymers, and also single molecules. They are versatile in many environmental, medical and diagnostic uses because of their ability to incorporate more components into their form and because of the three dimensional shape. Thus the dendrimers have been studied in several subjects including biochemistry, biotechnology and chemistry with respect to their structure and composition. They have shown potential to be used as antiviral, antifungal as well as antibacterial, besides being used as catalysts. For example, peptide dendrimers have been studied for the delivery of genes, antigens, synthetic vaccines and MRI contrast agents. This review mainly focuses on the variety of dendrimers, methods of their preparation as well as brief information on their limitations and potential use in the therapy of infectious diseases (Filipczaket al., 2021).

Inorganic Nanoparticles

1. Silver nanoparticles
2. Gold nanoparticles
3. Copper nanoparticles
4. ZnO nanoparticles
5. Iron oxide nanoparticles.

Silver Nanoparticles

It is fast developed field with multiple applications and special features mentioned by Almatroudi (2020). Nanomedicine can be described as the clinical application of nanotechnology in the combating as well as management of diseases. Silver nanoparticles in this discipline is one of the most important. The nanoparticles being particles with size between 1 and 100 nm.. They can create different shape when working at the nanoscale level and possess variety features. The best known biomedical applications of Ag NPs include the direct bacterial and cancer cell killing, as well as enhanced wound healing. Also, they are cost-effective to create, and this is a conclusion that can easily be arrived at due to the following reasons. In this work, an attempt has been made to explore the different methods pertaining to physical, chemical and biological synthesis of silver nanoparticles. also is interested in the numerous medical applications of silver nanoparticles considering bone regeneration, tumor therapy, anti-infection, dental implant improvement, and wound recovery. The formation of silver nanoparticles, their mode of action and the techniques for studying the shape and structure of the nanoparticles are other topics addressed by the research in an effort to provide a clearer perspective of the part played by the nanoparticles in illness control and medicinal treatments.

Silver nanoparticles or in short AgNPs, are used in broad range of medical specialties and has been in the focus of attention as antibacterial materials. In developed studies it has demonstrated that the oral microbiota is not simply but rather intricate and the viable strains, which were unknown so far, have been identified. AMP is a small peptide that has been examined because of its invasive capacity of bacteria. In this work, a conjugate of the potent antibacterial peptide indolicidin with AgNPs was synthesised. The size and the optical properties of the AgNPs were analyzed with the help of optical spectroscopy and microscope. Gram positive and Gram negative bacteria were chosen for the experiment to check antibacterial properties of the coated nanoparticles done with oral samples. The results made clear that MIC of the coated nanoparticles was rather low and ranged between 5 to 12 only. Thus, 5µg/mL was effective in preventing the growth of bacteria, used for the experiment. Some examples are said to have suffered this due to the hallmarks of the indolicidin-coated metal surface. In addition, the elongated coated nanoparticles were proved less toxic than the peptide or the naked AgNPs when used individually. The biofilm reducing capabilities are AgNPs coated with AMPs are quite high, especially in oral infections, and require further research (Hamad et al., 2020).

Gold Nanoparticles

Thus, vaccinations that strengthen our immune system are perhaps the most effective protection against diseases (Dykman, 2020). As such, it is critically important to choose the right carrier to ensure a strong immune response in the process of manufacturing of antibodies or vaccinations. Determining an appropriate nanoscale particle transporter 'Gold nanoparticles' holds a lot of potential in this field. These are the immunogenic substances referred to as antigens and as Capable of encapsulating or adsorbing these, the microscopic particles are termed as such. In the process of vaccination, we can enhance the immunological effectiveness, using gold nanoparticles as carriers. Depending on which cells they stimulate and how they control the launch of antigens, they can act as adjuvants and enhance the potency of vaccinations (Figure 3). To raise the probabilities of using gold nanoparticles as a base for creating new vaccines against bacterial, viral, and parasitic diseases, one should study the human person's immunity to them as adjuvants and carriers.

Gold is shiny, that is why many people think of it as a royalty metal (Ko et al. , 2022). Some of them are its molecular recognition capacity, ease to process into shapes and forms and biocompatibility.

ZnO Nanoparticles

They are colourless powders, and are non-hazardous as they do not dissolve in water or alcohol (Deka et al., 2022). It possesses some attributes such as semiconducting and piezoelectric, which makes them to have many uses. Zinc oxide is enzymatically depositional, almost non-toxic and can be easily grafted with various materials on its surface. Zinc is one of the important trace minerals that are distributed in muscles, brain, skin, bones, and many other tissues. Nano-ZnO is a very small sized particle and gets easily penetrated and assimilated into the body and is used in food products. It is crucial to know the characteristics of nanoparticles particularly their shape and size and functionality for biological application. Using the biological and non-conventional synthesis of ZnO-NPs in this review, the ensuing applications of the ZnO-NPs include; anticancer, antidiabetic, antimicrobial, anti-inflammatory and antioxidant properties. ZnO-NPs also can be used as drug delivery systems, imaging and biosensors.

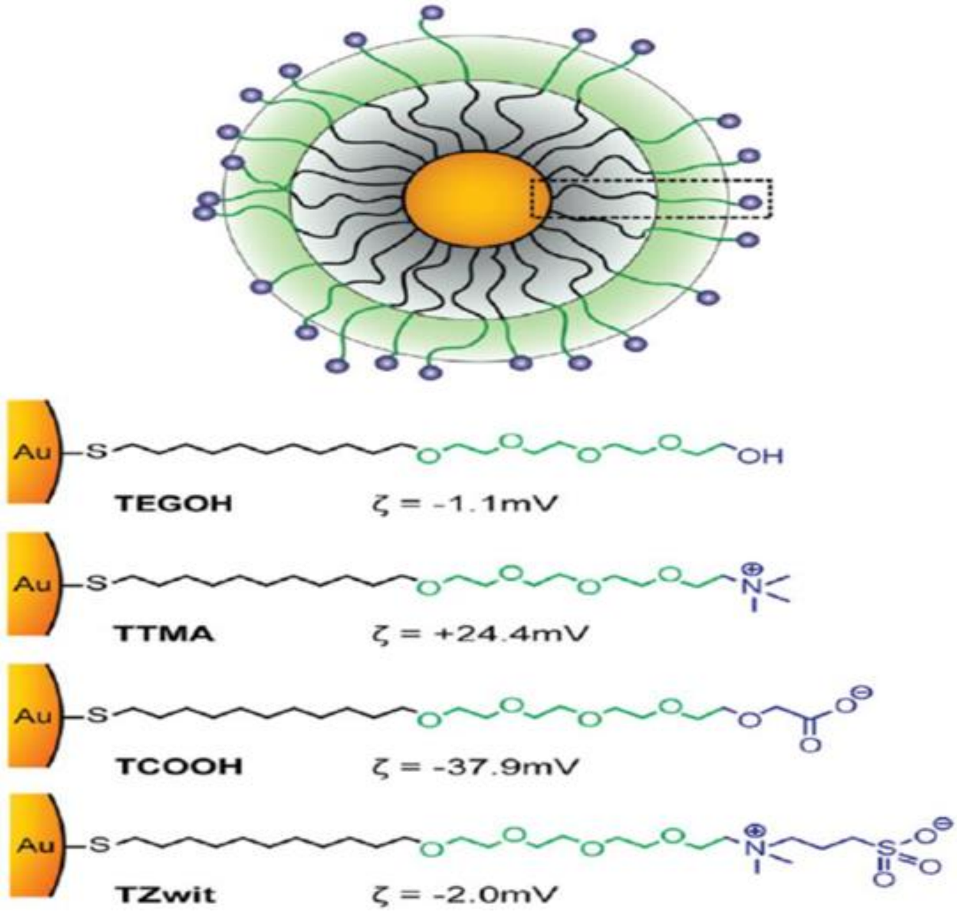

Fig. 3: (Structure of Gold Nanoparticle)

This study, thus, Cancer is a life-threatening illness precipitated by the development of new abnormal cells (Anjum et al., 2021). The approaches such as medications and chemotherapy are however restricted by low efficacy, availability of the limited stock and toxic impacts. The branch explores the medical applications of this coming field in nanotechnology, which is still in a state of development. Inorganic particles of very small dimensions, typically in the nanoscale, are prospective in cancer diagnosis and therapy due to the features of ZnO NPs. ZnO NPs cause specific cytotoxicity of cancer cells by producing ROS and causing cellular dysfunctions and final cell death. They also assist in introducing plant medical compounds as well as chemotherapy medicines to the tumor cells. This term paper focuses on the utilization of small zinc oxide particles on recognition of cancer cells and bioimaging. It focuses on the role of ZnO NPs as drug delivery systems and examines these issues as such: surface alteration, drug incorporation, and controlled release. It also summaries the anticancer property of ZnO NPs on various types of cancers and their perspective mechanisms. Also, it overviews the existing drawback and the probable future uses of ZnO NPs in cancer therapy.

Copper Nanoparticles

These are some of peculiarities of copper nanoparticles (CuNPs) which are perspective in the field of medicine (Ghasemi et al., 2023). Here, we described our study of the impact of copper nitrate on the oxidative stress and cell death in SW480 human colorectal cancer cell line. To determine the effect of CuNPs on cell viability we performed MTT assay after 24 hours. We quantified Reactive Oxygen Species (ROS) to determine oxidative stress or lack of it and we also determined antioxidant enzyme activity. To detect the cell death, the percentage of Hoechst33258 staining after treatment was assigned and the Bax, Bcl-2 and p53 proteins profiles were detected using qRT. The effect of CuNPs on SW480 viability was assessed by MTT assay and it was observed that CuNPs inhibited cell growth. There was a marked elevation of ROS production in all doses; 31, 68 and 100 µg/mL. CuNPs up regulated Bax and p53 as well as down regulated Bcl-2. Last but not the least the observations made using Hoechst staining that highlighted down the cell death. Taken together, the CuNPs were effective in evaluating the apoptotic effect and so CuNPs may be useful in anticancer effects.

Iron Oxide Nanoparticles

Iron oxide particles are the subject of this review which is subcategorized as magnetic nanoparticles (MNPs). MNPs show great promise in various medical applications like using electromagnetic heat, enhancing MRI data, aiding in tissue engineering, and improving drug delivery to challenging microenvironments. Their integration into medical treatments marks a significant growth in using advanced biotechnologies in healthcare. Superparamagnetic nanoparticles (SPNs) can be utilized by doctors to provide localized heat that eliminates bacterial biofilms, and they can also physically disrupt bacterial cell walls, making them more susceptible to antibiotics. Iron oxide nanoparticles (IONPs) enhance the delivery of bactericidal substances to microenvironments, showing potential in treating diseases that require therapeutic intervention, including those crossing the blood-brain barrier. This review thoroughly explores the use of magnetic iron oxide nanoparticles in treating bacterial diseases, focusing on their antimicrobial activity against bacteria (Lamichhane et al., 2021).

Nanobased Platforms for Cardiovascular Diseases

Cardiovascular diseases (CVDs) are a significant threat to public health, and traditional drug treatments face challenges like inefficiency and drug resistance. To address these issues, advanced methods for early detection and treatment are crucial. Nanotechnology and nanomedicine offer promising solutions by creating personalized diagnostic and therapeutic agents for CVDs. Nanoparticles act as tiny carriers delivering drugs effectively to damaged areas, addressing problems like bioavailability and solubility. They enable precise medication and gene delivery by binding to specific target molecules on their surfaces. In cardiology, nanoplatforms are popular due to their small size, facilitating easy penetration into heart and artery tissues, higher sensitivity and specificity, and passive or active targeting of cardiac tissues. However, concerns about nanoparticles' immunogenicity and cytotoxicity must be carefully considered (Shariati et al., 2023).

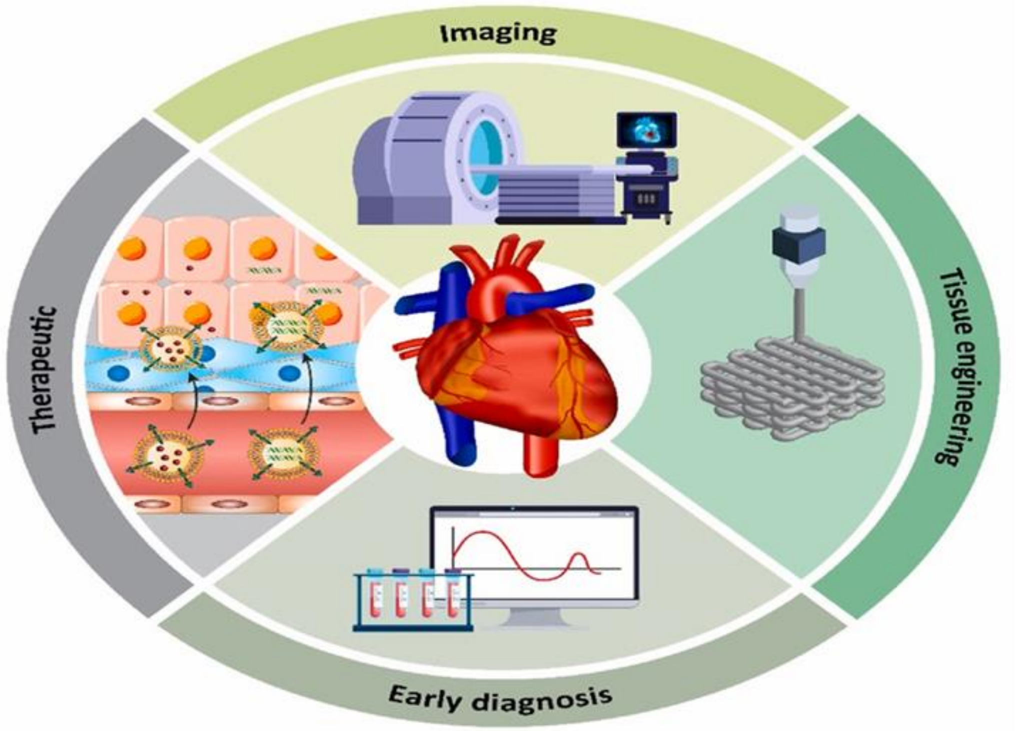

Fig. 4: Nanobased Platforms for Cardiovascular Diseases (Shariati et al., 2023)

Nanoparticles also show potential for imaging and diagnosing CVDs, providing simple diagnostic processes and real-time tracking during treatment. Nanotechnology has transformed cardiovascular imaging with multimodal, multifunctional vehicles outperforming traditional techniques. This overview discusses nanomaterial delivery methods, targeting strategies, and current developments in treating, diagnosing, and tissue engineering for CVDs (Figure 4). It explores future applications of nanomaterials in CVDs, aiming to improve cardiovascular care in clinical settings. Improving nanocarriers and delivery techniques could enhance therapy efficiency, reduce adverse effects, and improve patient outcomes (Zhong et al., 2022)

Antimicrobial Abilities of Metal Oxide Nanoparticles

The number of infectious diseases worldwide has increased significantly, with bacterial infections being a major cause of potentially fatal illnesses. Although progress has been made in treating bacterial diseases, the risk of death and illness remains high because bacteria are becoming resistant to commonly used antibiotics. In this era of increasing antibiotic resistance, it is crucial to find new ways to detect and develop advanced antibacterial agents to combat harmful bacteria.

Researchers are now exploring the potential of metal oxide-based nanoparticles, such as MgO, Ag2O, CuO, CaO, TiO2, and ZnO, for their antibacterial properties. These nanoparticles have tiny sizes that enable them to effectively interact with the active sites of microbes and disease-causing biomolecules due to their high surface-to-volume ratio. This has sparked interest in using metal oxide nanoparticles as next-generation antibacterial agents. Ongoing research on their antimicrobial properties aims to discover alternative solutions against antibiotic-resistant bacteria, making it a continuously growing and intriguing area of study (Panda et al., 2021).

Advantages of Nano Biotechnology

Nanomaterials offer a big boost to biomedical research by easily and strongly connecting with biological samples. This compatibility makes nanomaterials a valuable tool for improving various aspects of biomedical studies (Figure 5).

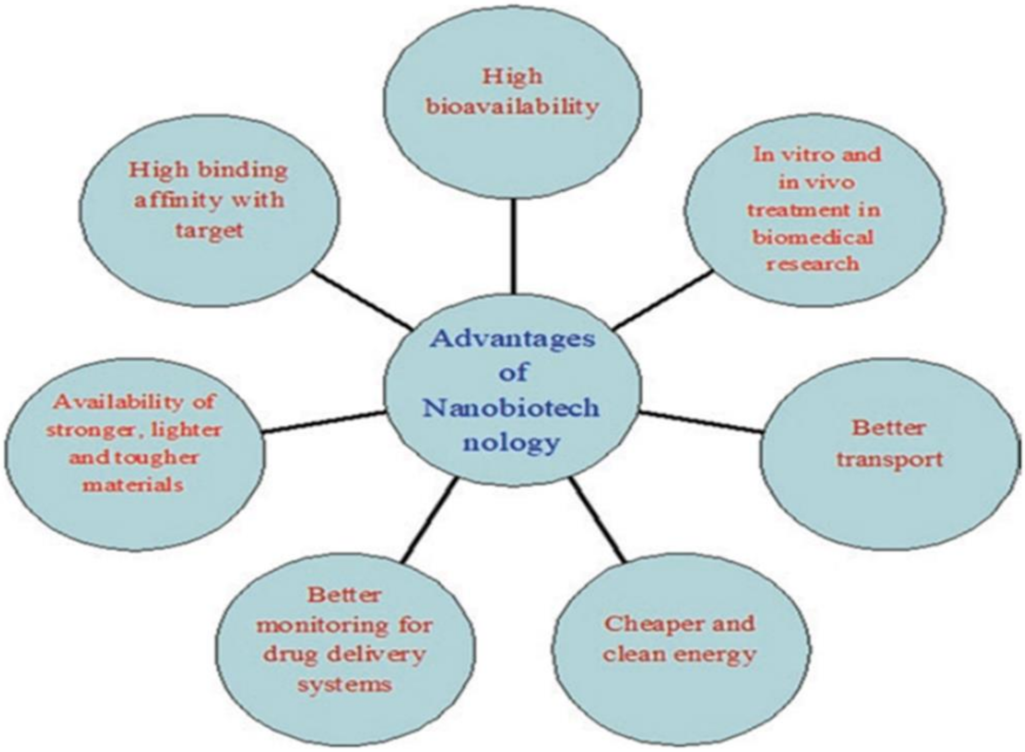

Fig. 5: Factors involved in the advancement nanobiotechnology in various research areas (Panda et al., 2021).

Potential Drug Delivery Pathways for Treatment of Alzheimer's Disease

Alzheimer's disease (AD), a common neurodegenerative condition affecting mostly those over 65, lacks effective medications despite substantial global spending on its treatment. The Blood-Brain Barrier (BBB) poses a challenge in treating brain diseases like AD as it restricts the entry of most drugs into the brain. After reviewing various publications from PubMed, a biomedical and life sciences journal archive, three potential drug delivery methods have been explored for their effectiveness in getting drug molecules into the brain: inorganic nanoparticles, multifunctional liposomes, and transdermal delivery systems. This research discusses a specific experiment supporting these delivery methods and provides a brief overview of each. It also examines the advantages and disadvantages of each delivery approach (Wang, 2022).

Nanotechnology against the Novel Coronavirus

COVID-19, a newly-emerging infectious disease, has significantly impacted society, leading to increased mortality and illness. Currently, there is no authorized vaccine or effective treatment for this pandemic. To tackle the virus, it's crucial to explore innovative methods, especially those involving nanotechnology. This review aims to present various ways to create COVID-19-resistant medicines and diagnostics using nanotechnology. Some promising strategies involve using polymeric materials, inorganic self-assembling materials, and peptide-based nanoparticles to combat and detect COVID-19. The review summarizes the exciting developments in using nanomaterials for preventing, diagnosing, and treating COVID-19 (Rashidzadeh et al., 2021).

Conclusion

In conclusion, a wide range of nanoparticle such as organic, polymer, liposome, micelle, dendrimer, and metal-based varieties like iron, gold, and silver, have innovative potential for the treatment of various diseases. Their particular characteristics boost medication methods of administration, increase the effectiveness of treatments, and allow for more precisely targeted therapies. Drug stability is increased by liposomes and micelles, while controlled distribution is facilitated by organic and polymer nanoparticles. Dendrimers offer versatility and targeted delivery, while metal nanoparticles bring antimicrobial properties and advances in imaging. Collectively, these innovations indicate an enormous development in medicine, opening up new avenues for modern healthcare and offering more effective, individualised treatments for a range of illnesses.

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