Innovations in Nanotechnology and Biotechnology for Combating Cancer, Malaria and Neurodegenerative Diseases

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Abstract

Nanotechnology is shifting the healthcare field through atomically modifying materials, especially in the areas of diagnostics and therapy. Nanoparticles with a size range from 1 to 100 nanometers are at the forefront of these developments and are utilized in targeted therapy, early illness detection, and precise drug administration. Early cancer diagnosis is accelerated by nanotechnology through the use of methods such as NIR quantum dots, gold nanoparticles, and nanoshells. It improves specificity and lessens damage to healthy tissues during medical operations, including radiation, chemotherapy, and X-ray therapy. Nanobiotechnology has increased the effectiveness of therapy for malaria through nanoparticle-based delivery techniques and nano vaccines, and it has improved diagnostic sensitivity using nanoparticle-functionalized biosensors. In treating neurodegenerative diseases such as Alzheimer's and Parkinson's disease, nanostructures like polymeric nanoparticles, nanocapsules, and nanomicelles present promising ways to get around obstacles like targeted drug delivery and the blood-brain barrier. This chapter discusses the latest developments in biotechnology and nanotechnology for the treatment of diseases like neurological disorders, cancer, and malaria.

Keywords: Nano-biotechnology, Cancer, Malaria, Neurodegenerative diseases, Drug delivery

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Introduction

Nanotechnology is the field of applied science and technology that focus on developing materials with novel and advanced properties at the atomic and molecular scale. Nanotechnology is the study and application of structures of different sizes ranging from 1-100nm (1nm= 10^{-9}m) (Lamberti, 2008). However, nano-biotechnology includes biological screening, chemical engineering, material science, mechanical synergy, electro-spinning, and microelectronics. Nanobiotechnology is the application of nanomaterials or nanodevices to biological processes, such as illness therapy. Nanotechnology helps the medical field grow quickly by combining engineering and medicine (Asadipour et al., 2023).

Nanoparticles are particles smaller than 100nm that possess new size properties in contrast to larger particles. Based on their properties, nanoparticles are categorized into a number of types as shown in Figure 1, including drug-conjugated protein nanoparticles, which are a type of nanomedicine that uses proteins to deliver drugs, liposomal nanoparticles, which are spherical nanocarriers used to deliver drugs and other bioactive materials, polymeric nanoparticles, which are solid particles made of natural or synthetic nanosized polymers (Malam et al., 2009). The other different sorts incorporate dendrimeric nanoparticles, which are circular, nano-sized particles with a clear cut structure and utilized in different applications, like medication conveyance and diagnostics, and hydrogels, which are three-layered networks made of hydrophobic polymers that are made by crosslinking water-solvent polymers (Tiwari & Tiwari, 2013).

The main progression in nanobiotechnology is the creation and utilization of nanoparticles and their uptake by the objective tissue. Nanobiotechnology provides excellent models to improve patient care (Asadipour et al., 2023). Nanotechnology offers different chances to work on the treatment of illnesses. It is recommended that nanobiotechnology convey the right medicine to the objective tissue at the right second with exactness, proficiency, speed, and security (Jain, 2005). Nanomedicine, also known as nano-biotechnology, is a rapidly developing field and the most innovative use of it is in the manufacturing of drug delivery systems at the moment. In the drug delivery system, the particles are designed in such a way that they are attracted toward the cells of the patient and make the environment perfect for the cells to receive the targeted treatment. This makes early diagnosis of disease and less damage to healthy cells (Wilczewska et al., 2012). This chapter explores the innovations in nanotechnology and biotechnology for combating cancer, Malaria, and neurodegenerative diseases.

Nano-biotechnology in Cancer

Cancer is the main cause of death and a significant global health problem. It was estimated that there would be 9.6 million deaths due to cancer and 18.1 million new cases of cancer by 2019 (Dakubo & Dakubo, 2019). Cancer is a disease that occurs when cells proliferate out of control and move to other areas of the body, and cause death. Early identification and therapy of tumors are essential for decreasing sickness spread and mortality. These days, quite possibly the most well-known approach in disease research is nanotechnology (Chaturvedi et al., 2019).

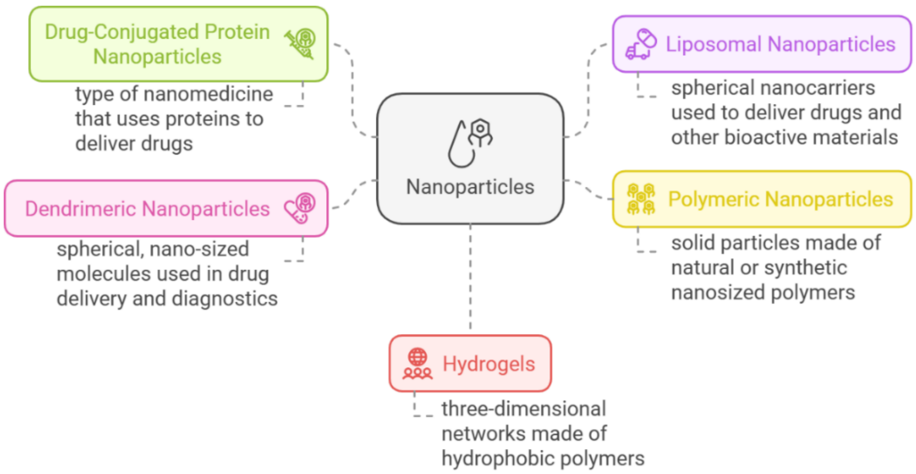

Fig. 1: Types of nanoparticles (Biorender)

Nano-biotechnology in Cancer Diagnosis

Tumors can be classified as malignant and benign. Benign tumors are restricted to the site of disease and don't spread to local tissues while malignant tumors are not restricted and effectively produce cells that spread to local tissues and different organs (Purysko et al., 2014). Early detection and stopping the growth and spread of cancerous cells to neighboring tissues are the goals of cancer diagnostic and therapeutic strategies. Computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and ultrasound are important early cancer diagnosis techniques (Saisho & Yamaguchi, 2004). These imaging techniques are restricted by their failure to give huge clinical information on the stage and different types of cancer. As a result, it can be difficult to get a comprehensive assessment of the disease that permits the administration of the most effective therapy (Bi et al., 2019).

According to studies published in different researches shows that cancer imaging at the tissue, cell, and subatomic level can be examined using nanotechnology (Moiz et al., 2025). For instance, the pH reaction to fluorescent nanoprobes can be utilized to recognize fibroblast-enacted protein-a on the cell film of growth-related fibroblasts (Dutta et al., 2025).

1. Near Infrared (NIR) Quantum Dots

Close to Infrared Quantum Dots are fluorescent gadgets that produce light in the near infrared locale (700-900nm) of the electromagnetic range. They are more reasonable for imaging lymphoma, pancreatic disease, liver malignant growth, and colorectal malignant growth (Cho, 2021). A second close infrared (NIR) window (NIR-ii, 900-1700 nm) has been created to make malignant growth imaging simpler. This wavelength range provides a higher temporal and spatial resolution and can penetrate deeper into tissue (Kenry et al., 2018). The creation of silver-rich Ag_2Te quantum dots (QDs) via a sulfur source has been explained as allowing for the identification of higher spatial goal images across a wide infrared spectrum (Sung et al., 2024).

2. Nanoshells

Dielectric cores with a diameter of 10–300 nanometers are called nanoshells. They typically consist of silicon and have a thin coating of metal, usually gold. These nanoshells can be optically adjusted flexibly using UV-infrared emission/absorption arrays and function by converting electrical energy mediated by plasma into light energy. Nanoshells are desired because their imaging lack of heavy metal toxicity, but the fact that their huge size restricts their application (Malhan et al., 2024).

3. Colloidal Gold Nanoparticles

Gold nanoparticles (AuNPs) can both actively and passively target cells. The permeability tension effect (EPR) in tumor tissues defines the passive targeting concept, which is a collection of gold nanoparticles to upgrade imaging. However, in order to achieve AuNP active targeting of tumor cells, AuNPs are coupled using tumor-specific targeted medications, for example EGFR monoclonal antibodies (Georgeous et al., 2024). Using X-ray imaging, researchers that combination AuNPs with liver cancer cells discovered the collection of the cancer cells in the gold nanocomposite set were noticeably larger and powerful than those in the liver cancer cells alone. These findings significantly affect early detection because the method can identify cancers as tiny as a few in the body millimeters in diameter (Her et al., 2017).

Cancer treatment using Nano-biotechnology

The treatment of cancer is one of the current issues facing medical science. Current therapies may include chemotherapy, radiation, and surgery, however, the results of these techniques may damage not only the tumor but also healthy tissue (Debela et al., 2021).

Nanobiotechnology is capable of revolutionizing the diagnosis and treatment of cancer. Nowadays, there are three ways to cure cancer: chemotherapy, radiation therapy, and surgery (Jin et al., 2020). These therapies also cause concerns for healthy tissues, which further explains each of these approaches and aids in the use of nanoparticles in these treatments (Mosleh-Shirazi et al., 2022).

A) Chemotherapy

Chemotherapy causes malignant tissue to accumulate TNFα, a tumor-killing factor. TNF attaches itself to the polyethylene glycol-coated gold nanoparticle (which is made from THIOL), making it immune system invisible. This will prevent the nanoparticle from being attacked as it moves through the bloodstream (Bhatia & Bhatia, 2016).

B) Radiation Therapy

Auro-Shell™ is a novel radiation therapy technique for eliminating cancerous tumors. Auro-shells are around 20 times smaller than red blood cells and consist of a silica core encased in a thin covering of gold (Sindhu et al., 2021). Auro-Shell™ nanoparticles enter through the bloodstream of the patient to cancer tissue vasculature. When nanoparticles accumulate inside tumor tissue, the tissue is exposed to infrared radiation. This radiation is absorbed by Auro-Shell™ nanoparticles, which then cause the tumor cells to specifically degrade through heat accumulation (Asadipour et al., 2023).

C) X-ray Therapy

Among the nanoparticles that have a strong potential for X-ray therapy-induced tumor tissue destruction is NBTXR3. In this procedure, NBTXR3, also known as PEP503, is directly injected into tumors using a syringe. X-rays stimulate the NBTXR3 nanoparticles, and electrons are released from these nanoparticles that destroy tumor tissue. As such, the tumor cell is broken down. Healthy cells and tissues are least in danger from this sort of radiation. (Asadipour et al., 2023).

Nano-biotechnology in Malaria

Plasmodium parasites spread malaria, an infectious disease that is conveyed by infected Anopheles mosquitoes. Malaria is a serious global health issue, particularly in places with limited access to medical care (Kogan & Kogan, 2020). Malaria is one of the biggest causes of morbidity and mortality worldwide and with estimation, it caused 229 million cases and over 400,000 fatalities in 2019 alone (Patel et al., 2024). Rapid diagnostic tests (RDTs) and microscopy are instances of traditional demonstrative techniques with restricted awareness, particularly for people with low parasitemia. Two significant obstacles for antimalarial drugs are emerging resistance and inadequate absorption (Hanboonkunupakarn & White, 2022). Nanotechnology offers better approaches to take care of these issues with delicate diagnostics, further developed drug conveyance strategies, and precise focusing (Dessale et al., 2022).

Nano-biotechnology in Malaria Diagnosis

For the management and control of malaria, a prompt and precise diagnosis is crucial. Nanotechnology can improve the sensitivity, specificity, and accessibility of conventional malaria diagnostic methods in detecting low parasitemia cases particularly (Guasch-Girbau & Fernàndez-Busquets, 2021).

Rapid diagnostic tests (RDTs) are utilized to analyze malaria in view of their convenience and speedy reaction (Wongsrichanalai et al., 2007). The use of nanoparticles, such as gold nanoparticles (AuNPs) and magnetic nanoparticles (MNPs), has improved performance on RDT platforms. When contrasting AuNPs functionalized with antibodies or aptamers to standard RDTs, the first may detect malaria-specific biomarkers at lower parasite levels due to their higher sensitivity (Ha et al., 2018).

Nanostructured biosensors have a high sensitivity and specificity for detecting malaria biomarkers (Krampa et al., 2020). These biosensors record and transform molecular interactions into measurable signals and offer immediate identification. Nanomaterials' affinity for malaria antigens is enhanced when functionalized with specific receptors or aptamers, allowing immediate diagnosis with minimal sample preparation (Ragavan et al., 2018).

Nano-biotechnology in the Treatment of Malaria

Nanobiotechnology targets the parasite directly and offers effective treatment options for the eradication of malaria. The following are a couple nano-biotechnological drives that make treating malaria simple and secure.

a) **Nanoparticle-based Drug Delivery Systems:** Nanoformulations increase the effectiveness of currently available antimalarial medications by improving absorption, extending their half-lives, and targeting parasites within host cells (Keleş et al., 2024). To enhance absorption by infected cells and prevent degradation, hydrophobic antimalarial medications like chloroquine or artemisinin derivatives can be encapsulated in lipid-based nanoparticles, polymeric nanoparticles, or nanocrystals (Alven & Aderibigbe, 2020). Antimalarial drugs can be precisely delivered to erythrocytes or hepatocytes infected with *Plasmodium* using functionalized nanoparticles. Modifying the surface with ligands specific to parasite receptors encourages selective absorption, lowering side effects and the amount of medication needed (Kunjiappan et al., 2021). This method improves medication effectiveness and delays the emergence of drug resistance.

b) **Nanovaccines and Immunotherapeutics:** Nanotechnology gives novel platforms for the development of malaria vaccines by facilitating controlled release kinetics, boosting immunogenicity, and improving antigen storage (Borgheti-Cardoso et al., 2020). Adjuvants with a nanostructure, including lipid-based nanoparticles or virus-like particles (VLPs), encourage strong immune responses and provide persistent protection against Plasmodium species. It is possible to create nanoparticles to alter immunological responses, strengthening the host's defenses against malaria parasites. When paired with antimalarial medications or vaccines, immunomodulatory nanoparticles loaded with cytokines, immunostimulatory molecules, or RNA-based therapies enhance both innate and adaptive immune responses and provide synergistic effects (Lima et al., 2023).

Nano-biotechnology in Neurodegenerative Disease

The term "neurodegeneration" describes the state in which neurons in the central and peripheral nervous systems deteriorate. When it affects the central nervous system, it results in symptoms such as amyotrophic lateral sclerosis, Parkinson's disease, Huntington's disorders, Alzheimer's disease, and other less frequent illnesses (Jellinger, 2010). Alzheimer's disease (AD) causes approximately 60% of dementia, which affects over 24 million people globally. Alzheimer's disease affects 1% of people between the ages of 50 and 70, and its prevalence rapidly rises to 50% of people over 70 (Association, 2019). Alzheimer's disease is a biological process that starts when amyloid plaques and neurofibrillary tangles, which are protein accumulations, accumulate in the brain. As a result, the brain gradually shrinks and its cells die (Ahmed et al., 2018).

The most common symptoms of Parkinson's disease (PD) include bradykinesia, rigidity, and resting tremor, which are caused by the irregular deterioration of nigrostriatal dopaminergic neurons in the midbrain and a subsequent decrease in brain dopamine (DA) levels. One percent of those over 65 have Parkinson's disease (PD). At most 5% of cases are familial or hereditary, indicating that genetic aspects are distinctly rare (Radhakrishnan & Goyal, 2018).

The biggest challenge to treating all NDs remains the delivery of drugs to the due to the numerous protective barriers that envelop the central nervous system. The development of nanotechnology may provide a way to overcome these challenges with Alzheimer's disease and Parkinson's diagnosis and neurotherapy (Ning et al., 2022). Therefore, nanotechnology can be used to create tools for diagnosis and delivery systems that can bypass the blood-brain barrier to enable both traditional and innovative neurotherapeutic approaches.

Nanostructures used in Neurodegenerative Disease Treatment

Most drug delivery technologies used in nanotechnology to treat NDs are polymeric nanoparticles. The ability of polymeric nanoparticles to penetrate tight cell junctions, travel the blood-brain barrier, attain target the mutagenic proteins and possess a high drug-loading capacity in Alzheimer's disease and Parkinson's disease makes them suitable for treatment (Kumar et al., 2022).

Polymeric Nanoparticles, Nanocapsules, and Nanospheres

Nanocapsules and polymeric nanoparticles have a size range of 10–1000nm. Their strong drug-loading capabilities and ability to prevent degradation of the incorporated drug load increase the probability that the drug will reach the brain (Zorkina et al., 2020). Their capacity to change their surface properties to stay away from reticuloendothelial framework macrophage discovery makes them dependable and equipped for conveying medications to the focal sensory system (Wu et al., 2023). Drugs are dispersed all through thick polymeric lattices called nanospheres, which are made by miniature emulsion polymerization. Though the flimsy polymeric envelope of a nanocapsule encases an oil-filled empty, the strong center of a nanosphere is encircled by a thick polymeric grid.(Khalid & El-Sawy, 2017).

Polymeric Nanogels and Nanosuspensions

Networks of cross-connected polymers, known as nanogels, are made by the emulsification dissolvable dissipation strategy and commonly involve ionic and nonionic polymeric chains. (Mauri et al., 2021). Particles like oligonucleotides, siRNA, DNA, proteins, and low-sub-atomic mass prescriptions can be remembered for nanogels on the grounds that they enlarge in water. Drug-stacked nanosuspensions comprise of glass like drug particles balanced out by lipid blends or nonionic surfactants. The straightforwardness, high medication stacking limit, and reasonableness for a large number of prescriptions for CNS conveyance are a portion of the primary advantages of nanosuspensions (Zingale et al., 2022).

Polymeric Nanomicelles

Polymeric nanomicelles have a center shell structure, with a hydrophilic polymer block shell encompassing a hydrophobic center. The center can forestall early medication debasement and delivery by amounting to 20-30% w/w of hydrophobic drugs. (Movassaghian et al., 2015). While keeping the nanomicelles steady, the shell prevents the medication from communicating with serum proteins and bothersome cells. After arriving at the objective cells, the medicine is delivered through dispersion. (Tewabe et al., 2021).

Polymeric Nanoliposomes

The vesicular designs known as nanoliposomes are made out of uni-or multilamellar lipid bilayers encasing inward water compartments. Presenting similarly a lot of medications to the lipid bilayers or the fluid compartments of liposomes is conceivable. (Bozzuto & Molinari, 2015). Longer fundamental dissemination times can be accomplished by nanoliposomes with changed surfaces that lessen opsonization in plasma and the liver and spleen's capacity to perceive and eliminate them. To assess nanoliposomes for designated CNS drug conveyance, various applications have been examined.(Terstappen et al., 2021).

Conclusion

Biotechnology and nanotechnology have made it possible to identify, cure, and prevent neurological disorders, malaria, and malignant development. Nanotechnology has significantly enhanced cancer imaging through NIR, quantum dots, nanoshells, and gold nanoparticles while also improving treatment outcomes and reducing damage to healthy cells. For malaria, nanotechnology has improved rapid diagnostics by using nanostructured biosensors and treatment efficacy by developing novel nanoparticle-based drug delivery systems and nanovaccines. Nanostructures have shown extraordinary potential in the treatment of neurodegenerative diseases by precisely focusing on the harmed brain regions and crossing the blood-brain barrier (BBB). Even though nanobiotechnology is still in its beginning stages of research, it can profoundly change medical care all around the world. These technologies have the potential to greatly improve patient outcomes, treat illnesses more effectively, and help create a future where complex diseases are treated more precisely and with fewer side effects if they can overcome their current limitations.

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