Applications of Nanotechnology in Cell and Molecular Biology

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Abstract

To allow unique methodologies in a variety of biological applications, nanoparticles can be produced with specific compositions, sizes, shapes, and surface chemistries. Fundamental biological concerns may be studied in novel and interdisciplinary ways because to the special characteristics of nanoparticles and how they behave in biological environments. An overview of the numerous nanoparticle kinds and nanoparticle targeting theories will be provided in this review. We will also go through the benefits and most current uses of nanoparticles as instruments for medication administration, imaging, sensing, and the comprehension of fundamental biological processes.

Keywords: *Nanotechnology, Cell Biology, Molecular Biology*

Introduction

Nanotechnology is a relatively young field of study that has a wide range of uses, including the creation of energy, industrial production methods, and biomedical applications. The fields of biology and biomedical research are two of the main applications. It is possible to design nanoparticles (NPs) to have a distinctive composition and functions, which can lead to the development of brand-new methods and instruments for biomedical research. NPs can be employed, for instance, to visualise biological processes at the cellular level. They are also capable of detecting molar range analytes. In this overview, we will talk about the many kinds of NPs and how they could be used in biological and biomedical research [1].

Types of Nanoparticles

NP platforms come in a variety of shapes, sizes, compositions, and capabilities. Additionally, different fabrication methods may be used to create each kind of NP, such as nanoprecipitation and lithography for polymeric NPs. While a detailed discussion of the variations in NP platforms and their manufacture is outside the purview of this work, we will still go over the key traits and functionalities of each NP that are important for biological research.

Liposomes

The liposomes served as the first NP platform. In 1965, liposomes were introduced as a model for biological membranes. Since that time, liposomes have evolved from a biophysical study model to one of the first NP platforms used for the delivery of genes and medications. Liposomes are spherical vesicles made of lipids that self-assemble into a single or multiple bilayered structure in aqueous conditions. Liposomes have special benefits that include a wide variety of compositions, the capacity to carry and safeguard a variety of biomolecules, as well as biocompatibility and biodegradability. Due to these benefits, liposomes have been extensively studied and used in biology research as agents for the transfection of genetic material into cells (lipofection). Typically, a cationic lipid forms an aggregation with the anionic genetic material during lipofection. Since its architecture enables the trapping of hydrophilic substances in the core and hydrophobic medicines in the lipid bilayer itself, liposomes are also widely used as therapeutic carriers. Liposomes have been coupled with biocompatible polymers like polyethylene glycol (PEG) to increase their stability in vivo and circulation half-life. In order to maximise the accumulation of diagnostic and therapeutic substances within selected cells, liposomes can also be functionalized with targeting ligands. Twelve medicinal medicines based on liposomes are now authorised by clinical trials [2].

Albumin-bound

The endogenous albumin routes are used by albumin-bound NPs (nab) to transport hydrophobic compounds into the circulation. Albumin naturally forms non-covalent reversible bonds with hydrophobic compounds, preventing solvent-based toxicities for therapeutic purposes. This platform has therefore been effectively adopted as a means of medication delivery. The FDA authorised Abraxane, a 130-nm nab paclitaxel, in 2005 for the treatment of metastatic breast cancer. Abraxane accumulates in cells thanks to endothelial cells' ability to transport it via the albumin receptor (gp60). The albumin-binding protein SPARC (secreted protein acidic and rich in cysteine), which is overexpressed in some tumours, may potentially be a potential target. Improved targeting and the creation of new treatments employing the nab platform may result from a deeper knowledge of the mechanism of action [3].

Polymeric

As therapeutic carriers, polymeric NPs made from biocompatible and biodegradable polymers have been thoroughly studied. Through the use of block-copolymers with various hydrophobicities, polymeric NPs are created. In an aqueous setting, these copolymers spontaneously coalesce into a core-shell micelle structure. In addition to proteins and nucleic acid macromolecules, polymeric NPs have been designed to encapsulate hydrophilic and/or hydrophobic small medicinal molecules. Drug release at target areas may be gradual and regulated thanks to the NP design. Drugs carried by polymeric NPs often have greater safety and effectiveness. Since polymeric NPs are special in that they may be modified before particle formation, functionalizing them with targeted ligands for better drug delivery has been a crucial field of research. The addition of targeting ligands to NPs may boost both their uptake and the uptake of their cargo, improving therapeutic results. Dendrimers are another another kind of polymeric NP. Regularly branching macromolecules known as dendrimers are created from synthetic or natural components such as nucleotides, sugars, and amino acids. They consist of an outer surface, an inner layer of branches, and a central core. These elements may be combined in a variety of ways to produce dendrimers with clearly specified size, shape, and branching length/density. Dendrimers may be created as sensors, as well as vehicles for the delivery of drugs and genes, because of their distinctive design. Through chemical bonding, hydrogen bonds, or hydrophobic contact, dendrimers can be loaded with tiny molecules in the cavities of the cores. Additionally, it is simple to generate chemical functional groups on the outer surface for molecular targeting, imaging and detecting agents, and medicinal attachment sites [4, 5].

Iron oxide

As they are primarily superparamagnetic, iron oxide NPs are extensively researched as a passive and active targeted imaging agent. The hydrophilic layer of dextran or another biocompatible substance is often applied to the iron oxide core of superparamagnetic iron oxide nanoparticles (SPION) to boost their stability. The most popular SPIONs have a core made of magnetite (Fe_3O_4) or maghemite (Fe_2O_3). These NPs have size-dependent superparamagnetism, which enables them to be magnetised when an external magnetic field is applied and to have zero net magnetization when the magnetic field is removed. SPIONs have been utilised to track and monitor cells using T2-weighted magnetic resonance (MR) contrast agents.

In comparison to traditional gadolinium-chelate contrast agents, SPIONs provide a number of benefits, such as reduced toxicity and improved imaging sensitivity and specificity. SPIONS may also be broken down into molecules of iron and iron oxide, which are then processed, stored in cells as ferritin, and combined with haemoglobin. Currently, ferumoxides (120–180 nm) and ferucarbotran (60 nm), two SPIO drugs, have received clinical approval for MRI. SPIONs have also been applied to molecular imaging tasks including apoptosis and gene expression identification. For multimodal imaging, SPIONs can be functionalized with magnetic, optical, radionuclide, and particular targeting ligands. They may also be utilised as non-invasive diagnostic techniques and as means of medicine administration [6].

Quantum dot

Quantum dots (QDs), semiconductor particles with a diameter of less than 10 nm, were first identified in 1980. Unique size-dependent electrical and optical features may be found in QDs. The majority of researched QDs have a core made of cadmium selenide (CdSe) and a cap made of zinc selenide (ZnS). These particles have extremely wide absorption spectra, and their emission is restricted to a small band. QDs are durable against photobleaching, have long lives, excellent efficiency, and may produce vivid colours. They may be produced with various biochemical specificities and aroused and detected at the same time. For optical applications, QDs therefore provide a number of important benefits over numerous organic fluorophore dyes. They are often employed as fluorescent imaging tools in biological research for tasks like cell labelling and biomolecule tracking. Due to their tiny size, quantum dots are especially well suited for biological uses including imaging and diagnostics [7].

Gold

Gold nanoparticles (gold NPs) have numerous optical and chemical characteristics that rely on size and shape, are biocompatible, and are simple to surface modify. Due to the special way that the free electrons in the NP interact with light, gold nanoparticles can significantly improve optical processes such light absorption, scattering, fluorescence, and surface-enhanced Raman scattering (SERS). These characteristics have made it possible to use gold nanoparticles in a variety of applications, including biochemical sensing and detection, biological imaging, diagnostics, and therapeutic uses.

In order to greatly increase Raman scattering, gold nanoparticles are used in colorimetric arrays and as substrates in SERS. These sensing methods enable the spectroscopic detection and identification of proteins and single molecules at the NP surface. Gold NP probes have also been utilised to find biomarkers for cancer and heart disease. They have a strong potential for infrared phototherapy since they can also convert absorbed light into heat [8, 9].

Conclusions

Numerous biological uses exist for NPs and nanotechnology. As was already noted, nanotechnology makes it possible to design objects that are the same size as individual cells and biomolecules. This opens up new possibilities for imaging, sensing, drug administration, and the characterization of fundamental biological processes. There is grounds for great optimism for more inventive and intriguing uses of NPs in biology because the interest in biological applications for NPs is relatively new. Biological investigations that make use of NP approaches can offer fresh perspectives on how complicated signalling networks affect how cells behave and what happens at the molecular level. NPs may also be utilised to better understand how these processes might be improved and how different parts of a cell cooperate to carry out a task.

Acknowledgements

Authors are very much thankful to Head of Department of Zoology, Sant Gadge Baba Amravati University, Dist. Amravati, Maharashtra – 444602 for providing necessary academic help.

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