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Applications of Nanoparticles In Biology

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ABSTRACT

At the forefront of the quickly evolving discipline of nanotechnology are nanomaterials. These materials are outstanding and indispensable in many areas of human activity because of their special size-dependent characteristics. This concise overview aims to provide an overview of the latest advancements in the field of applied nanomaterials, including their use in biology and medicine, and addresses the potential for commercialization. Because of their customisable surface properties and large range of core materials, nanoparticles are a great platform for a wide range of biological and medicinal applications. An overview of nanoparticle–biomolecular interactions and current uses of nanoparticles in biological sensing, delivery, and imaging of living cells and tissues are given in this review.

Keywords: *Nanomaterials, nanotechnology, Nanoparticles, Biology*

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INTRODUCTION

Technology that works with things the size of nanometers is made possible by nanotechnology [1]. It is anticipated that nanotechnology would advance across multiple domains, including systems, devices, and materials. Right now, the state of nanomaterials is the most developed in terms of both scientific understanding and practical uses. Because of their size-dependent physical and chemical properties, nanoparticles were explored ten years ago [2]. They are currently in a phase of commercial exploration [3,4]. The cells that make up living things are usually 10 µm in diameter. On the other hand, the sub-micron size range corresponds to the considerably smaller cell components. Proteins are even smaller, typically measuring only 5 nm, which is about the same size as the tiniest artificial nanoparticles. The concept of utilising nanoparticles as minuscule probes to spy on the cellular machinery without interfering too much is suggested by this straightforward size comparison [5]. A major factor propelling the advancement of nanotechnology is our growing understanding of biological activities at the nanoscale [6].

Biology and material science are combined when nanoparticles are used in biotechnology. Nanoparticles offer a particularly helpful platform because of their distinct characteristics and potential for a wide range of therapeutic uses.[7] The projected number of papers in the field of nanoparticles in biology increased from 11 in 1991 to approximately 10,000 in 2007 (based on Web of Science). This indicates that the field is undoubtedly growing. Since we obviously cannot cover the area in full detail, this Review offers a concise synopsis of recent investigations utilising spherical nanoparticles with metallic, metal oxide, semiconductor, and silica cores. A number of characteristics give nanoparticles their special qualities and applications, including their resemblance in size to biomolecules like polynucleic acids and proteins. Furthermore, a variety of metal and semiconductor core materials can be used to create nanoparticles, giving them beneficial characteristics including magnetic and fluorescent behaviour.[8]

Nanoparticle–Biomolecule Interactions

Nanoparticles acting as synthetic receptors that recognise the surfaces of macromolecules offer a potential means of regulating intracellular and extracellular activities for a wide range of biological applications, including delivery, sensing, transcription regulation, and enzymatic inhibition. Depending on the core material, nanoparticle core sizes can range from 1.5 nm to more than 10 nm, offering an appropriate platform for interactions between nanoparticles and proteins and other biomolecules (Fig. 1).[9] There are two methods for conjugating nanoparticles with biomolecules, like proteins and DNA: direct covalent bonding and non-covalent interactions between the particle and the biomolecule.[10–15] Covalent attachment is the most straightforward method for producing integrated biomolecule-nanoparticle conjugates. [16] Either the biomolecule chemisorbs to the particle surface or heterobifunctional linkers are used to accomplish this conjugation. Proteins can chelate onto the surface of nanoparticles (which typically have a core composed of Au, ZnS,

CdS, and CdSe/ZnS) chemically using 2-iminothiolane (Traut's reagent) or by utilising cysteine residues found on protein surfaces (such as those found in serum albumin and oligopeptides)[17].[18]

A very flexible method for the biofunctionalization of nanoparticles is offered by non-covalent assembly. There are several ways to bind DNA to NP: electrostatic interactions, complementary single-strand DNA binding, intercalation, and groove binding. [19] Nanoparticles provide an attractive receptor for nucleic acids, providing a direct analogy to protein–DNA interactions.[20,21]

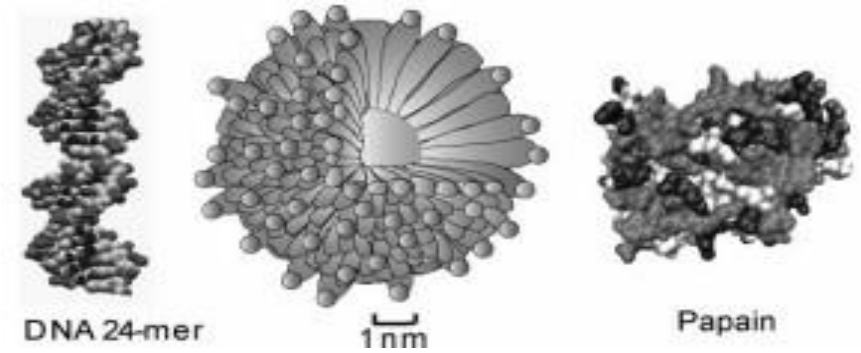

Figure 1. Schematic representation of a 2 nm gold nanoparticle with 11-mercaptoundecanoic acid monolayer and relative sizes of papain and a 24-mer DNA duplex.

Nanoparticles in Biosensing

Forensic science, environmental monitoring, and biomedical diagnosis all depend on the ability to detect diseases, biological agents, and harmful compounds.[22] A recognition element for target binding and a transduction element for signalling the binding event are the two main parts of a sensor. NPs have special physicochemical properties[9], and miniaturisation naturally increases signal-to-noise ratios[23], which makes these systems attractive options for sensing applications.[24] For instance, depending on their size and form, gold nanoparticles display distinct optical and electrical characteristics. Gold nanoparticles exhibit a strong absorption peak that originates from surface plasmon resonance (SPR) between 500 and 550 nm [25].[26–28]

APPLICATIONS

A list of some of the applications of nanomaterials to biology or medicine is given below: - Fluorescent biological labels [29-31]

- Drug and gene delivery [32,33]
- Bio detection of pathogens [34]
- Detection of proteins [35]
- Probing of DNA structure [36]
- Tissue engineering [37,38]
- Tumour destruction via heating (hyperthermia)[39]
- Separation and purification of biological molecules and cells [40]
- MRI contrast enhancement [41]
- Phagokinetic studies [42]

As was previously indicated, nanomaterials are appropriate for biotagging or labelling since nanoparticles reside in the same size domain as proteins. But size is only one of many properties of nanoparticles that, by itself, are rarely enough to employ them as biological markers. A biological or molecular coating or layer functioning as a bioinorganic interface needs to be affixed to the nanoparticle in order for it to interact with the biological target.

Antibodies, biopolymers like collagen [43], or monolayers of tiny molecules that render the nanoparticles biocompatible [44] are a few examples of biological coverings. Furthermore, as biological research frequently uses optical detection techniques, nanoparticles must to glow or alter their optical characteristics. The approaches used in constructing nano-biomaterials are schematically presented below (see Figure 2)

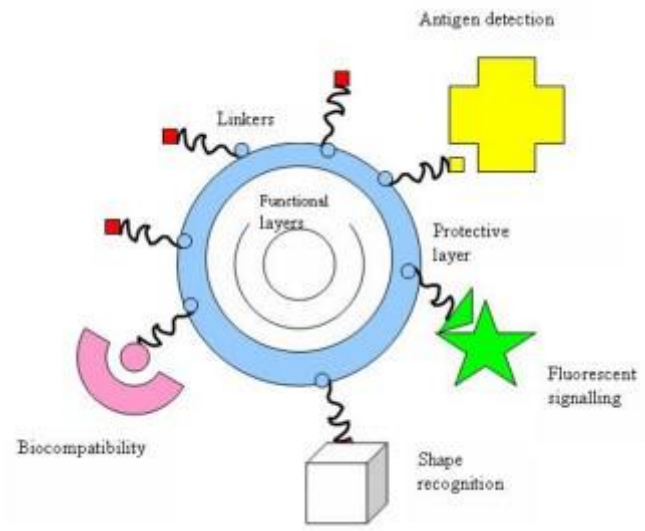

Figure 2; Typical configurations utilized in nano-bio materials applied to medical or biological problems.

RECENT DEVELOPMENTS

Tissue engineering

Features measuring roughly 100 nm wide are frequently found on the surface of natural bones. The body would attempt to reject an artificial bone implant if its surface were left smooth. Owing to its smooth surface, the implant's surface is probably going to develop fibrous tissue covering it. This layer lessens the contact between the implant and the bone, which could cause the implant to loosen and cause further inflammation. It has been shown that adding nanoscale characteristics to the surface of a hip or knee prosthesis can both increase the growth of osteoblasts and lower the likelihood of rejection. On the advancing surface of the growing bone are cells called osteoblasts, which are in charge of the formation of the bone matrix. Materials made of polymeric, ceramic, and, more recently, metal, were used to illustrate the effect. Only 50% of the human bone cells in the control sample attached to the nanostructured metal surface, compared to almost 90% of the cells in suspension [45]. Ultimately, these discoveries would enable the development of more robust and long-lasting hip or knee replacements while also decreasing the likelihood of implant loosening.

Cancer therapy

The foundation of photodynamic cancer therapy is the cytotoxic atomic oxygen produced by lasers, which destroys cancer cells. When compared to healthy tissue, the cancer cells absorb more of a particular dye that is used to produce atomic oxygen. As a result, only the cancer cells that have been eliminated are subjected to laser radiation. Regretfully, the patient becomes extremely sensitive to sun exposure due to the residual dye molecules migrating to their skin and eyes. Up to six weeks may pass before this effect fades. The hydrophobic dye molecule was encased in a porous nanoparticle to prevent this negative effect [46].

Multicolour optical coding for biological assays

The development of high throughput screening technologies is necessary due to the growing amount of sequence data generated by proteomics and genomic studies. Saturation is anticipated to occur for different array technologies that are currently being employed in parallel analysis when the number of array elements surpasses several millions.

The number of distinct tags that can be consistently generated and identified is the single constraint on a three-dimensional method that relies on optical "bar coding" of polymer particles in solution. Compound semiconductor single quantum dots have been effectively employed in place of organic dyes in a variety of bio-tagging applications [48]. By mixing variously sized quantum dots—which thus have diverse luminous colors—into polymeric microbeads, this concept has been expanded upon [47].

Manipulation of cells and biomolecules

Numerous uses for functionalized magnetic nanoparticles have been reported, such as cell separation and probe [8], which are covered along with other uses. The majority of magnetic particles that have been investigated thus far are spherical, which somewhat restricts the potential for these nanoparticles to have many functions. By inserting the metal electrode position into the nanoporous alumina template, alternative cylindrically shaped nanoparticles can be produced [49]. The radius of the nanocylinders can be chosen between 5 and 500 nm, and their length can reach up to 60 µm, depending on the characteristics of the template. It is possible to widely adjust the structure and magnetic characteristics of individual cylinders by successively depositing varying metal thicknesses.

CONCLUSIONS

An extremely appealing platform for a wide range of biological applications is provided by nanoparticles. These systems' surface and core properties can be designed for both singular and multimodal applications, including as biomolecular identification, biosensing, bioimaging, and medicinal delivery. Many different in vitro and in vivo uses of nanoparticles have previously been made. However, in order to fully realise their promise, a number of unresolved concerns must be resolved. These include the acute and long-term health consequences of nanomaterials, as well as scalable, repeatable manufacturing processes and trustworthy metrics for characterising these materials.

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