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NANOBIOCHEMISTRY: A REVOLUTION IN MODERN BIOSCIENCES

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ABSTRACT

Nanotechnology is a branch of technology, which is concerned with the fabrication, study and application of materials in the form of very small particles. Nanotechnology has revolutionized biological chemistry. The application of nanotech in research has aided the study and understanding of many biochemical processes. The field of biochemistry is increasing by leaps and bounds due to the help provided by nanotechnology. It had become possible for scientists to examine intricate molecular structures and mechanisms more broadly like never before .Nanotechnology has many applications in biochemistry such as drug delivery, diagnosing diseases, food safety testing and much more. Nanotechnology is a rapidly growing field with tremendous potential for the future. It will change the way we live, work and interact with each other - providing new tools to solve societal challenges of managing natural resources, climate change and sustainable development. . This brief research paper tries to summarise the most recent developments in the field of applied nanomaterials, in particular their application in biochemistry, and discusses their commercialisation prospects.

INTRODUCTION

The science of nanotechnology deals with the creation, investigation and utilization of systems that are 1000 times smaller than the components currently used in the field of microelectronics. Biotechnology deals with metabolic process with microorganisms. Convergence of these two technologies results in growth of nanotechnology in Biochemistry. The biomedical applications of nanotechnology are the direct products of such convergences. The challenges facing by the scientists and engineers working in the field of nanotechnology are quite enormous and extraordinarily complex in nature. Nanotechnology in biochemistry presents many revolutionary opportunities in the fight against all kinds of cancer, cardiac and neurodegenerative disorders, infection and other diseases. Researchers at the Lawrence Berkeley National Laboratory (Berkeley Lab) & the University of California at Berkeley are combining nanotechnology with biochemistry, which resulted in discovery of unique synthetic membranes that enable them to directly control signaling activity in living T cells from the immune system. In this way nanotechnology and biochemistry will definitely bring out many challenging research works in the upcoming days. As time passes, engineered nanoparticles (ENPs) are more frequently found in medical and consumer products, as well as in industrial and agricultural applications. The intensive production, use, and disposal of ENPs-containing wastes increase the likelihood of emission of such products to the environment. During the last two decades, a body of scientific literature has shown that ENPs interact with living components of ecosystems in different ways. The literature indicates that ENPs impact on plant growth, cell structure, and physiological and biochemical functions. In this chapter we discuss the stress induced by ENPs on higher plants. Although some references about carbon-based ENPs are included, most of the references are related to metal-based ENPs. The discussion is mainly focused on the effects of ENPs on photosystems and the mechanisms of generation/scavenging of reactive oxygen species (ROS). Effects on the enzymes catalase

(CAT), guaiacol peroxidase (GPOX), ascorbate peroxidase (APOX), superoxide dismutase (SOD), glutathione reductase (GR), and dehydroascorbate reductase (DHAR) are discussed. Information about low molecular weight antioxidant thiols (GSSG or GSH) and ascorbate is also included. Nano-particle usually forms the core of nano-biomaterial. It can be used as a convenient surface for molecular assembly, and may be composed of inorganic or polymeric materials. It can also be in the form of nano-vesicle surrounded by a membrane or a layer. The shape is more often spherical but cylindrical, plate-like and other shapes are possible. The size and size distribution might be important in some cases, for example if penetration through a pore structure of a cellular membrane is required. The size and size distribution are becoming extremely critical when quantum-sized effects are used to control material properties. A tight control of the average particle size and a narrow distribution of sizes allow creating very efficient fluorescent probes that emit narrow light in a very wide range of wavelengths. This helps with creating biomarkers with many and well distinguished colours. The core itself might have several layers and be multifunctional. For example, combining magnetic and luminescent layers one can both detect and manipulate the particles. The core particle is often protected by several monolayers of inert material, for example silica. Organic molecules that are adsorbed or chemisorbed on the surface of the particle are also used for this purpose. The same layer might act as a biocompatible material. However, more often an additional layer of linker molecules is required to proceed with further functionalisation. This linear linker molecule has reactive groups at both ends. One group is aimed at attaching the linker to the nanoparticle surface and the other is used to bind various moieties like biocompatibles (dextran), antibodies, fluorophores etc., depending on the function required by the application.

RECENT DEVELOPMENTS

Tissue engineering

Natural bone surface is quite often contains features that are about 100 nm across. If the surface of an artificial bone implant were left smooth, the body would try to reject it. Because of that smooth surface is likely to cause production of a fibrous tissue covering the surface of the implant. This layer reduces the bone-implant contact, which may result in loosening of the implant and further inflammation. It was demonstrated that by creating nano-sized features on the surface of the hip or knee prosthesis one could reduce the chances of rejection as well as to stimulate the production of osteoblasts. The osteoblasts are the cells responsible for the growth of the bone matrix and are found on the advancing surface of the developing bone. The effect was demonstrated with polymeric, ceramic and, more recently, metal materials. More than 90% of the human bone cells from suspension adhered to the nanostructured metal surface [1], but only 50% in the control sample. In the end this findings would allow to design a more durable and longer lasting hip or knee replacements and to reduce the chances of the implant getting loose. Titanium is a well-known bone repairing material widely used in orthopaedics and dentistry. It has a high fracture resistance, ductility and weight to strength ratio. Unfortunately, it suffers from the lack of bioactivity, as it does not support cell adhesion and growth well. Apatite coatings are known to be bioactive and to bond to the bone. Hence, several techniques were used in the past to produce an apatite coating on titanium. Those coatings suffer from thickness non-uniformity, poor adhesion and low mechanical strength. In addition, a stable porous structure is required to support the nutrients transport through the cell growth. It was shown that using a biomimetic approach – a slow growth of nanostructured apatite film from the simulated body fluid – resulted in the formation of a strongly adherent, uniform nanoporous layer [2]. The layer was found to be built of 60 nm crystallites, and possess a stable nanoporous structure and bioactivity. A real bone is a nanocomposite material, composed of hydroxyapatite crystallites in the organic matrix, which is mainly composed of collagen. Thanks to that, the bone is mechanically tough and, at the same time, plastic, so it can recover from a mechanical damage. The actual nanoscale mechanism leading to this useful combination of properties is still debated. An artificial hybrid material was prepared from 15–18 nm ceramic nanoparticles and poly (methyl methacrylate) copolymer [3]. Using tribology approach, a viscoelastic behaviour (healing) of the human teeth was demonstrated. An investigated hybrid material, deposited as a coating on the tooth surface, improved scratch resistance as well as possessed a healing behaviour similar to that of the tooth.

Biosensors

Biosensor is an analytical device which is used to detect a biological product. In the development of biosensors, nanotechnology is playing an increasingly important role. The nanotechnology based biosensor or nanobiosensor technology is revolutionizing the health care industry such as the nanobiosensor technology is used in the measurement of metabolites, monitoring of diabetes etc., forensic medicine, homeland security. In food and drink industry these are used for remote sensing of water quality, determination of drug residue in food etc. For environment protection these are used in the detection of pesticides and river water contaminants like heavy metal ions, and genome analysis of organisms and communications. The use of nanomaterials for the construction of biosensors has improved the sensitivity and performance of them, and has allowed the introduction of many new signal transduction technologies in biosensors[4,5]. The development of tools and processes used to fabricate, measure and image nanoscale objects, has led to the development of sensors that interact with extremely small molecules that need to be analysed. Several nanobiosensor architecture based mechanical devices, optical resonators, functionalised nanoparticles, nanowires, nanotubes and nanofibers have been in use. In particular, nanomaterials such as gold nanoparticles, carbon nanotubes, magnetic nanoparticles and quantum dots have being actively investigated for their application in biosensors, which have become a new interdisciplinary frontier between biological detection and material science. With the advent of nanotechnology and its impact on developing ultrasensitive devices, it can be stated that it is probably one of the most promising way to solve some of the problems concerning the increasing need to develop highly sensitive, fast and economic method of analysis in medical diagnostics, food and drink industry, environment protection etc.

Structural DNA nanotechnology

Structural DNA nanotechnology is derived from naturally occurring structures and phenomena in cellular biochemistry. Motifs based on branched DNA molecules are linked together by sticky ends to produce objects, periodic arrays, and nanomechanical devices. The motifs include Holliday junction analogues, double and triple crossover molecules, knots, and parallelograms. Polyhedral catenanes, such as a cube or a truncated octahedron, have been assembled from branched junctions. Stiff motifs have been used to produce periodic arrays, containing topographic features visible in atomic force microscopy; these include deliberately striped patterns and cavities whose sizes can be tuned by design. Deliberately knotted molecules have been assembled. A periodic arrangements of DNA tiles can be used to produce assemblies corresponding to logical computation. Both DNA structural transitions and branch migration have been used as the basis for the operation of DNA nanomechanical devices. Structural DNA nanotechnology has been used in a number of applications in biochemistry. An RNA knot has been used to establish the existence of RNA topoisomerase activity. The sequence dependence of crossover isomerization and branch migration at symmetric sites has been established through the use of symmetric immobile junctions. DNA parallelogram arrays have been used to determine the interhelical angles for a variety of DNA branched junctions. The relationship between biochemistry and structural DNA nanotechnology continues to grow.

Protein detection

Proteins are the important part of the cell's language, machinery and structure, and understanding their functionalities is extremely important for further progress in human well being. Gold nanoparticles are widely used in immunohistochemistry to identify protein-protein interaction. However, the multiple simultaneous detection capabilities of this technique are fairly limited. Surfaceenhanced Raman scattering spectroscopy is a well-established technique for detection and identification of single dye molecules. By combining both methods in a single nanoparticle probe one can drastically improve the multiplexing capabilities of protein probes [6]. The group of Prof. Mirkin has designed a sophisticated multifunctional probe that is built around a 13 nm gold nanoparticle. The nanoparticles are coated with hydrophilic oligonucleotides containing a Raman dye at one end and terminally capped with a small molecule recognition element (e.g. biotin). Moreover, this molecule is catalytically active and will be coated with silver in the solution of Ag(I) and hydroquinone. After the probe is attached to a small molecule or an antigen it is designed to detect, the substrate is exposed to silver and hydroquinone solution. A silverplating is happening close to the Raman dye, which allows for dye signature detection with a standard Raman microscope. Apart from being able to recognise small molecules this probe can be modified to contain antibodies on the surface to recognise proteins. When tested in the protein array format against both small molecules and proteins, the probe has shown no cross-reactivity.

Nanotechnology in Cancer Diagnosis

Metallic nanoparticles conjugated to peptides have been prepared from Au and iron oxide (magnetic nanoparticles) (7). Several peptide-nanoparticle conjugates show biocompatibility and present a low degree of cytotoxicity. Furthermore, several peptide-metallic nanoparticle conjugates are used for in vitro diagnosis (8, 9). Nanoparticles of cadmium selenide (quantum dots) glow when exposed to ultraviolet light. When injected, they seep into cancer tumors. The surgeon can see the glowing tumor, and use it as a guide for more accurate tumor removal. Sensor test chips containing thousands of nanowires, able to detect proteins and other biomarkers left behind by cancer cells, could enable the detection and diagnosis of cancer in the early stages from a few drops of a patient's blood (9). Nanotechnology offers a wide range of tools, from chipbased nanolabs capable of monitoring and manipulating individual cells to nanoscale probes that can track the movements of cells, and even individual molecules, as they move about in their environment. Using such tools will enable cancer biologists to study, monitor, and alter the multiple systems that are implicated in cancer processes and identify key biochemical and genetic targets for future molecular therapies. As such, nanotechnology can complement other technology platforms, such as proteomics and bioinformatics. Another near-term application of nanotechnology to accelerate basic research is to use molecular-size nanoparticles with a wide range of optical properties (e.g., quantum dots) to track individual molecules or cells as they move through local environments, thereby monitoring multiplexed cellular and molecular events in real time. When combinedwith mouse models that reproduce the genetic, biochemical, and physiological properties of human cancers, these nanolabels will be useful for integrative, systems biology research. Finally, nanoscale devices that enable simultaneous biochemical measurements (e.g., time, size, dynamic events) on multiple cells, particularly those grown in such a way as to mimic tissue development in vivo, will bring new dimensionality to basic cancer research.

Commercial Explorations

The majority of the companies are small recent spinouts of various research institutions. Although not exhausting, this is a representative selection reflecting current industrial trends. Most of the companies are developing pharmaceutical applications, mainly for drug delivery. Several companies exploit quantum size effects in semiconductor nanocrystals for tagging biomolecules, or use bio-conjugated gold nanoparticles for labelling various cellular parts. A number of companies are applying nano-ceramic materials to tissue engineering and orthopaedics. Most major and established pharmaceutical companies have internal research programs on drug delivery that are on formulations or dispersions containing components down to nano sizes. Colloidal silver is widely used in antimicrobial formulations and dressings. The high reactivity of titania nanoparticles, either on their own or then illuminated with UV light, is also used for bactericidal purposes in filters. Enhanced catalytic properties of surfaces of nano-ceramics or those of noble metals like platinum are used to destruct dangerous toxins and other hazardous organic materials.

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