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Review on a Nanomaterials Mechanisms-Induced Oxidative Stress and Toxicity

Geetha N[1,2], Prabhavathi G[1,2], Ayeshamariam A[1,2]*, Beevi AH[3], Punithavelan N[4], Uthiram C[4] and Jayachandran M[5]

[1]*Research and Development Centre, Bharathiar University, Coimbatore-641 046, India*
[2]*Department of Physics, Kunthavai Nachiyar Government Arts College for Women, Thanjavur, 613 007, India*
[3]*Research and Development Center, Weifang Conqueren Bioscience and Technology Co. Ltd., Weifang City, 261000, China*
[4]*School of Advanced Sciences in Physics, Vellore Institute of Technology, Chennai Campus, Chennai, 600 127, India*
[5]*Department of Physics, Sethu Institute of Technology, Pullor, Kariyapatti, 626 106, India*

Abstract

The review reveals the recent trends of nano-materials in biomedical applications and an overview to discuss the commercialization of nano-materials. Due to innovative ideas in nano-materials created a lot of new discoveries in the medical, consumer sectors and industrial applications. The properties of nano-materials lead to a quite interest in a various applications in biomedical field such as structural and physicochemical properties. In a biological activity; toxicities of a nanoparticle are frequently reported. In the presence of acellular factors such as size, composition, particle surface and presence of metals in a nano-materials induces oxidative stress and it creates a pathway for patho physiological effects includes fibrosis, genotoxicity and injuries in a skin. Zinc oxide acts as an antioxidant for reducing oxidative stress and it acts as a protective agent for an immune system in a biomedical fields. This review summarizes biomedical applications of a nano-materials and the role of an oxidative stress.

Keywords: Antibacterial; Antifungal; Biomedical; Oxidative stress; Biomaterials

Introduction

Nanotechnology plays a vital role in many applications in the different areas of medicine, biotechnology, electronics, drug delivery, aerospace engineering, material science, cosmetics and biosensors. The properties of nano-materials have a wide range of applications in medicine, clothing and cosmetics. The properties raise a various probability factors in a day-to-day environmental process such as in a metal based nanoparticle and carbon nanotubes, due to the presence of intrinsic properties, it increases wide applications in commercial products [1-2]. In optoelectronics, inorganic nano-materials such as nano rods, nanowires and quantum dots are used due to very interesting optical and electrical properties. The properties of nano-materials mainly depend on their size and shape of a nanomaterial. By using different synthetic techniques, size and shape of nano-materials can be tuned. Organic solar cells, OLEDS etc., are the applications of optoelectronic devices based on an inorganic material. The principle of an optoelectronic devices mainly based on photoinduction process such as electron and energy transfer. Devices depend upon the efficiency of photo induction and it is important criteria to understand the process used in both organic/Inorganic nano-materials, which can be used in organic/inorganic optoelectronic devices. In biomedical applications, nano-materials regenerate biological tissues, generating cures and artificial proteins are also manufactured. In the upcoming years, computers can be manufactured using biochemical and organic salts. The parameters of nano-materials created wide research interests in its toxic behavior [3]. Fabrication of micro technology-based smart devices in both silicon and flexible materials, for online biofilm monitoring including different sensors impedance, pH, dissolved oxygen and ion concentration. Development of flexible sensing devices to evaluate the corneal barrier function in a non-invasive way by measuring the bio impedance changes of the different co meal layers. To study the oxidative stress, nano-materials have been deposited directly on inside organelles or on the cellular surface. This review describes the biomedical applications based on metal based nano-materials.

Reactive oxygen species generation

Hydroxyl radical, singlet oxygen and superoxide peroxides are a chemically reactive chemical species which contains oxygen [4]. In cell signaling and homeostasis, reactive oxygen species are formed as a natural byproduct of metabolism of oxygen [5]. Reactive oxygen species (ROS) increases due to an environmental stress (e.g., UV or heat exposure) and results in significant damages to cell structures namely oxidative stress [6]. ROS are studied on a variety of species. The role of ROS has positive effects such as induction of genes and ion mobilization systems. It implies a controlled cellular function. ROS acts on a cardiovascular disease, programmed cell death or apoptosis and ischemic injury. Species examples are stroke and heart attack. Harmful effects in reactive oxygen species are to damage RNA or DNA oxidations of polyunsaturated fatty acids in lipids, oxidation of amino acids in proteins, oxidative specific enzymes. The principle mechanism of cytotoxicity in metal oxide particles is to induce ROS [7]. The generation of free radicals influence active transcription factors, intracellular calcium concentrations and modulate cytokine production.

Cancer therapy

For a destruction of cancer cells, photodynamic cancer therapy is used. This principle is based on a laser generating atomic oxygen. Special dyes are used for generating reactive oxygen species and it is used for the treatment for a cancer, to remove the cancer tissues when it is

***Corresponding author:** Ayeshamariam A, Research and Development Centre, Bharathiar University, Coimbatore-641 046, India, Tel: 9486738806; E-mail: aismma786@gmail.com

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exposed to a light radiation. The side effect can be resolved by enclosing the dye molecule inside a porous nanoparticle [8] and it is not spread to any other parts of the body. By using dyes, generating oxygen would not be affected and nanoparticles allow the oxygen freely to diffuse out. Nanosized materials such as silver are used in pharmaceutical companies as antimicrobial formulations and dressings.

Antibacterial agent delivery

The antibacterial properties of ZnO-doped TiO_2 nano-materials have also been investigated in recent years [9]. ZnO-doped Ti-based nano-fibers promote antimicrobial effects against *Escherichia coli* and *Staphylococcus sp.* in the presence of cell membrane disruption and cytoplasmic leakage. The following materials $ZnCl_2/TiO_2$, Zn $(Ac)_2/TiO_2$, Zn $(NO_3)_2/TiO_2$, and $ZnSO_4/TiO_2$ follows the subsequent order: $ZnSO_4ZnCl_2$ Zn $(NO_3)_2$ Zn(Ac) $_2$, can be used as antibacterial agents and the highest antibacterial activity has been observed for $ZnSO_4/TiO_2$ and is possibly ascribed to improved surface acidity [10]. It has also been reported that zinc can be incorporated into titanium dioxide to achieve good bacterial inhibition ability [11].

Mechanisms of a nanoparticle-induced oxidative stress

Nano-materials such as CNT, fullerenes and metal oxides are induced by oxidative stress. The three factors in nanoparticles induce reactive oxygen species are mainly (i) proxidant functional groups present in a reactive surface of a nanoparticle (ii) In a transition metal-based nanoparticle, active redox cycling acts and (iii) Particle-cell interactions. In a reactive oxygen species (ROS), sources mainly depend on the particle-cell interactions and physicochemical parameters.

Interaction of a particle-cell via oxidation generation

Nano-materials are self-oxidative in nature and reacts with cells to induce reactive oxygen species and activate the NADPH - like enzyme systems. In lung epithelial cells, alveolar macrophages (AM) and neutrophils are the ROS inducers. Phagocytic cells including neutrophils and alveolar macrophages induce the reactive oxygen species in the internalization of nanoparticles. The physicochemical properties of nano-materials attribute the phagocytic oxidation in the internal parts. In silica and quartz particles, inflammation induces ROS due to surface based radical generating properties in nano-materials. Adsorption of chemicals in a nanoparticle surface drives the oxidation stress (Table 1).

Potential risks

Nanotechnology marketing risks for human health and environment depends upon the toxicity. By using cosmetics and medicine, nanoparticles entered the human body and accumulate in cells. The health effects of such nanoparticles are unknown. Historical experience with unintended consequences of technologies, such as drug resistance to antibiotics or the persistence of chemicals such as DDT in the environment, teaches us to take precautions. Long, Jeffrey [12] of the Naval Research Laboratory (Washington, DC) points out that viruses are already nano biotechnological objects and that humankind's history with viruses reinforces the need for continuous monitoring of the potential effects of newly designed and fabricated nano-materials. A European commission–National science foundation workshop held early this year discussed the societal aspects of nanotechnology. Participants concluded [13] "Nano-biotechnology could dramatically improve public health, but there is concern that technical developments could cause unforeseen adverse effects. Studies are needed to determine what environmental and health risks are associated with nanomaterial." Medical nanotechnologies are entering industrial production, mainly for diagnostics, drugs, and therapies. In the longer term, nanotechnology may help improve implants and even let blind people see. Nonetheless, governments must stimulate scientists to monitor possible health risks of nanoparticles that may accumulate in the body [14-20].

Biosensors

Modern technologies provide powerful tools to fabricate the porous structures of biomaterials and to enhance the natural biosynthetic systems for targeted applications [21]. Porous architectures have been fabricated using different techniques, such as solvent casting, particulate leaching, gas foaming, phase separation, electro spinning, porogen leaching, fiber mesh, rapid prototyping, and freeze drying, to meet the requirements of different applications**.** Biosensors, a biological sensing element and a specific molecular recognition which is often used to generate the concentration dependent signals [22]. Several biopolymers are available for microbial encapsulation in porous matrices to hold the microorganisms for water purification, bio molecule production, and ethanol production. Attempts have been made to remove heavy metals and organic pollutants from contaminated water using porous bio-matrices. Bio-based porous materials have been used to incorporate antimicrobial agents to food packaging materials for food preservation. Porous materials prepared from biopolymers also play a key role in energy conservation and heat reduction by acting as thermal insulators in building constructions [23]. The sensitivity and specificity depend on the biological recognition system [24,25]. Since the development of enzyme-based sensors for glucose by Clark and Lyons [26], improvements have been made in terms of the sensitivity, selectivity, and reproducibility as a result of rapid developments in nanotechnology

Oxidants	Description
O_2-, superoxide anion	One-electron reduction state of O_2, formed in many auto oxidation reactions and by the electron transport chain. Rather un reactive but can release Fe_2^+ from iron-sulfur proteins and ferritin. Undergoes dismutation to form H_2O_2 spontaneously or by enzymatic catalysis and is a precursor for metal-catalyzed OH formation [14].
H_2O_2, hydrogen peroxide	Two-electron reduction state, formed by dismutation of $•O_2$- or by direct reduction of O_2. Lipid soluble and thus able to diffuse across membranes [15].
•OH, hydroxyl radical	Three-electron reduction state, formed by Fenton reaction and decomposition of peroxynitrite. Extremely reactive, will attack most cellular components [16].
ROOH, organic hydro peroxide	Formed by radical reactions with cellular components such as lipids and nucleobases [17].
RO•, alkoxy and ROO•, peroxy radicals	Oxygen centred organic radicals. Lipid forms participate in lipid per oxidation reactions. Produced in the presence of oxygen by radical addition to double bonds or hydrogen abstraction [18].
HOCl, hypochlorous acid	Formed from H_2O_2 by myeloperoxidase. Lipid soluble and highly reactive. Will readily oxidize protein constituents, including thiol groups, amino groups and methionine [19].
ONOO-, peroxynitrite	Formed in a rapid reaction between $•O_2$- and NO•. Lipid soluble and similar in reactivity to hypochlorous acid. Protonation forms peroxynitrous acid, which can undergo homolytic cleavage to form hydroxyl radical and nitrogen dioxide [20].

Table 1: Oxidants and its description.

and nano-materials-based biosensors. In order to improve the performance of biosensors, TiO_2 nano-materials such as nanoparticles, nano-fibers encapsulated TiO_2 nano-composites have been used in bio-sensing devices for enzymes, antibodies, microorganisms, and DNA. Nanostructured TiO_2 biosensors are sensitive, selective, fast, and reproducible for the detection of various chemical and biochemical compounds such as glucose, hydrogen peroxide, and cancer cells because of their superior properties including nontoxicity, large surface area, uniform and excellent biocompatibility. Hepatocytes survive in 3D matrices prepared with various types of polymers, such as collagen, proteoglycan, fibronectin, and laminin. Porous chitosan scaffolds were fabricated by lyophilization for cultivation of rat hepatocytes. Scaffolds with a porosity of 90% and mean pore sizes ranging from 50 µm to 200 µm were obtained using this method. Hydroxyapatite is a main constituent of bone mineral and widely used as a bioactive material for bone tissue engineering applications. Hydroxyapatite and gelatin composite scaffolds were prepared using solvent casting combined with freeze drying. Results showed that the prepared scaffold had an open, interconnected porous structure with a pore size of 80-400 nm [27].

Conclusion

The incorporation of biomedical and biosensor in the advance instruments have its own advantages when compared to the conventional detection techniques as it is selective, sensitive, robust, convenient, and rapid detection methods employed in medical, agriculture and food related field. The introduction of nano-materials in applications provides us with opportunities for establishing a new generation of biomedical technologies. Nanomaterial's based applications have great attention in the process control, food analysis, biomedical and in industries. In future, developing effective technologies for rapid production of large amounts of nanomaterial based high quality specifications and relatively low cost will be of huge interest. Also, further research studies should focus on developing multifunctional nano-material's and making the biomedical technology more robust and accessible.

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