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Development of ZnO Nanoparticles for Clinical Applications

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Abstract: Nanomaterials have a great many medical applications which are growing rapidly to lead the wide scale production and application of engineered nanoparticles. Extension of nano engineering to the formation of fibers, sheets and volume-filling materials such as gels, networks and scaffolds as well as other none medical products such as cosmetics, sunscreens and food products are increasing. However, extensive usage of them may cause unwanted damages and toxicity to the living cells due to the increased surface reactivity of nanoparticles. The properties of many conventional materials will be changed when they are in nanoparticle form. This is typically because nanoparticles have a greater surface area per weight than larger particles which make them to be more reactive to some other molecules. In recent years ZnO nanoparticles have been used in different industrial sectors such as medicine, cosmetic materials and concrete, anti bacterial, textile and automotive industries. ZnO is currently being investigated as an antibacterial agent in both microscale and nanoscale formulations. Results have indicated that ZnO nanoparticles show antibacterial activity apparently greater than microparticles.

Keywords: Nanoparticles, ZnO, Antibacterial, Antimicrobial and Medical Applications.

INTRODUCTION

The field of nanotechnology is one of the most active research areas in modern materials science. Nanoparticles exhibit new or improved properties based on specific characteristics such as size, distribution and morphology. There have been impressive developments in the field of nanotechnology in the recent past years, with numerous methodologies developed to synthesize nanoparticles of particular shape and size depending on specific requirements. New applications of nanoparticles and nanomaterials are increasing rapidly[1]. Nanotechnology can be termed as the synthesis, characterization, exploration and application of nanosized materials for the development of science. It deals with the materials whose structures exhibit significantly novel and improved physical, chemical, and biological properties, phenomena, and functionality due to their nano scaled size. Because of their size, nanoparticles have a larger surface area than macro-sized materials. The intrinsic properties of metal nanoparticles are mainly determined by size, shape, composition, crystallinity and morphology. Nanoparticles, because of their small size, have distinct properties compared to the bulk form of the same material, thus offering many new developments in the fields of biosensors, biomedicine, and bio nanotechnology. Nanotechnology is also being utilized in medicine for diagnosis, therapeutic drug delivery and the development of treatments for many diseases and disorders. Nanotechnology is an enormously powerful technology, which holds a huge promise for the design and development of many types of novel products with its potential medical applications on early disease detection, treatment and prevention[2].

It is known that a biosensor is an analytical device, which converts the modification of the physical or chemical properties of a biomaterial into an electrical whose amplitude depends on the concentration of defined analytes in the solution. They are becoming essential in the field of medicine, healthcare, chemical and biological analysis, environmental monitoring and food processing industries[3]. It is well-established that ethanol sensors have wide applications in medical processes and food industries. One of the great candidates for fabrication of medical ethanol bio-sensor is ZnO nano-particle. It is known that ZnO particles have deodorizing and antibacterial properties and are used in food packaging. Furthermore ZnO is used to treat skin conditions in baby powder, barrier creams to treat diaper rashes, calamine cream, anti-dandruff shampoos and antiseptic ointments and medical bandage[4]. This material is one of the best choices for constructing gas sensors due to the sensitivity to gases e.g. NH_3, NO_2, CO, ethanol, etc. Among these applications, ethanol monitoring is substantially interested by medical scientists in breath analyzers and food control[5].

Zinc Oxide Nanoparticles: It usually appears as a white powder and is nearly insoluble in water. The powder is widely used as an additive for numerous materials and products including plastics, ceramics, glass, cement, rubber, lubricants, paints, ointments, adhesives, sealants, pigments, foods, batteries, ferrites, fire retardants, etc. ZnO is present in the Earth crust as a mineral zincite; however, most ZnO used commercially is produced synthetically. ZnO is nontoxic and is compatible with human skin making it a suitable additive for textiles and surfaces that come in contact with human body. The increase in surface area of nanoscale ZnO compared to bulk has the potential to improve the efficiency of the material function. The structure of zinc oxide surface has been computationally investigated using new atomistic potentials. **Fig.1** shows the crystal structure of ZnO. The bulk termination is also subject to high concentrations of dimer vacancies which correspond to fractional occupations in the surface layers[6]. Mechanical properties such as internal stress or adhesion are important in order to guarantee the patterning accuracy and durability for various types of commercial applications.

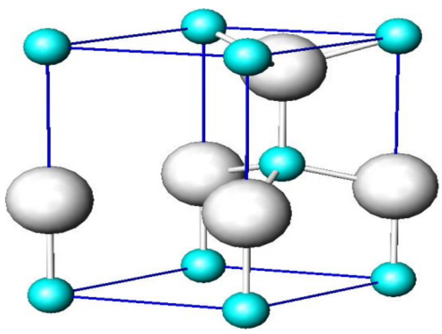

Fig.1: Crystal structure of ZnO

Antibacterial Activity of Zno Nanoparticles: Antibacterial agents are broadly of two types, organic and inorganic. At high temperatures/pressures organic antibacterial materials are found to be less stable compared to inorganic antibacterial agents. Thus ZnO has proved to be a powerful antibacterial agent in the formulation of the microscale and nanoscale systems for therapeutic applications. ZnO nanoparticles showed greater antibacterial activity apparently than microparticles. The exact mechanisms of the antibacterial action have not yet been clearly identified. ZnO particles have bactericidal effects on both Gram-positive and Gram-negative bacteria[7].

They even have antibacterial activity against spores which are resistant to high temperature and high pressure. From the literature it is evident that the antibacterial activity of ZnO nanoparticles depends on the surface area and concentration, while the crystalline structure and particle shape have little effect. Further it is also mentioned in the literature that smaller the size of ZnO particles better is its antibacterial activity. Thus higher the concentration and larger the surface area of the nanoparticles, the better is its antibacterial activity. The mechanism of the antibacterial activity of ZnO particles is still not well understood. Some researchers have proposed in their study that the generation of hydrogen peroxide is the main factor of the antibacterial activity, while it also indicated that the binding of the particles on the bacteria surface due to the electrostatic forces could be another factor[8].

Antimicrobial Potential of Zno Nanoparticles: ZnO is currently being investigated as an antibacterial agent in both microscale and nanoscale formulations. Results have indicated that ZnO nanoparticles show antibacterial activity apparently greater than micro particles. While the exact mechanisms of the antibacterial action have not yet been clearly understood, it has been suggested that the rule of reactive oxygen species (ROS) generated on the surface of the particles, zinc ion release, membrane dysfunction, and nanoparticles internalization are the main cause of cell swelling[9]. High temperature treatment of ZnO particles has a significant effect on their antibacterial activity. Treatment at a higher temperature leads to a lower activity.

The mechanisms of the antibacterial activity of ZnO particles are not well understood although proposed that the generation of hydrogen peroxide be a main factor of the antibacterial activity, while indicated that the binding of the particles on the bacteria surface due to the electrostatic forces could be a mechanism studied the antibacterial behaviour of ZnO particles by using a chemiluminescence and oxygen electrode analysis. Metal nanoparticles are highly ionic and can be prepared with extremely high surface areas and with unusual crystal and morphologies that possess numerous edge/corner and other reactive surface sites[10].

ZnO nanoparticles are being studied in combination with nonsurgical ablation regimens. In addition to better thermal effect on tumor ablation, nanoparticles can deliver anticancer therapeutics that show a synergistic antitumor effect in the presence of heat and can also be imaged to achieve precision in therapy. The molecular mechanism of nanoparticles mediated tumor ablation could further help engineer nanoparticles of appropriate composition and properties to synergize the ablation effect. The various types of nonsurgical tuor ablation method currently used in cancer treatment and potential improvements by nanotechnology application[11].

In the field of the research and development there are large amount of results obtained related to the ZnO nanoparticles, synthesis and its application. Preparation and utilization of ZnO nanoparticles are explored for the anti microbial effect in the fourth era. Due to the high polarity of the water, ZnO nanoparticles cause an immediate agglomeration during synthesis with water, which is a solvent system. Remedy was found for that, soluble starch was added before the reaction starts. The quick helical form of the soluble starch to protect and prevent the ZnO nanoparticles for agglomeration by action of steric hindrance. **Fig.2** shows the various mechanisms of antimicrobial activities exerted by nanomaterials[12].

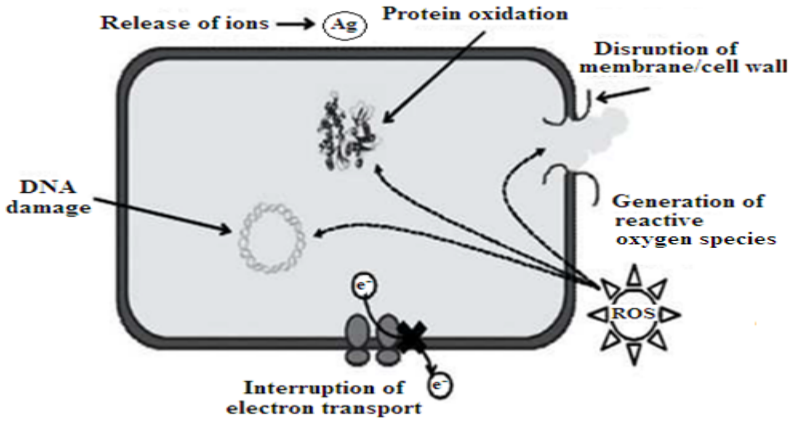

Fig.2: Various mechanisms of antimicrobial activities exerted by nanomaterials

Application of Zno: ZnO is no stranger to scientific study. For its potential of ultra violet absorbance, wide chemistry, piezoelectricity and luminescence at high temperatures, ZnO has entered into industry and now is one of the critical building blocks in today's modern society. It is found in paints, cosmetics, plastic and rubber manufacturing, electronics and pharmaceuticals. More recently however, it has again gained large interest for its semiconducting properties[13]. Among the oxide nanoparticles, ZnO nanostructure material has gained much interest owing to its wide applications for various devices such as solar cells, varistors, transducers, transparent conducting electrodes, sensors and catalysts. However, the properties of the pure bulk ZnO are not stable and cannot meet the increasing needs for the present applications. In order to modify the properties of the ZnO, this semiconductor material was usually doped with some dopants such as Al, Si, and Ga. For example, Al-doped ZnO increases its conductivity without impairing the optical transmission, which is regarded as a potential alternative candidate for ITO materials. Gas sensors based on ZnO had already been developed for detection and control of gases such as CO, H_2, H_2S, NH_3, etc.[14, 15]. ZnO nanoparticles embedded in polymer matrices like soluble starch are a good example of functional nanostructures with potential for applications such as UV-protection ability in textiles and sunscreens and antibacterial finishes in medical textiles and inner wears. ZnO nanoparticles have successfully been dispersed inside a soluble starch matrix using a simple water-based technique[16].

CONCLUSIONS

Nanoparticles, because of their small size, have distinct properties compared to the bulk form of the same material, thus offering many new developments in the fields of biosensors, biomedicine, and bio nanotechnology. In fact in nano dimension, percentage of surface moleculeCompare to bulk molecule is high and this enhances the activity of the particle in nano dimensionand therefore, the normal properties of the particle like heat treatment, mass transfer, catalytic activity, etc are all increases. But compare to non-metal nanoparticles, metal nanoparticles have more industrial application. Nanoparticles offer many new developments in the field of biosensors, biomedicine and bio nanotechnology. Among the oxide nanoparticles, ZnO nanostructure material has gained much interest owing to its wide applications for various devices such as solar cells, varistors, transducers, transparent conducting electrodes, sensors and catalysts. ZnO nanoparticles are one of the most abundantly used nanomaterials in consumer products and biomedical applications due to their specific properties, e.g. transparency, high isoelectric point, biocompatibility and photocatalytic efficiency. They are widely employed in a variety of devices including cosmetics, toothpaste, sunscreens, fillings in medical materials, textiles, wall paints and other building materials.

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