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Applications of transition metal nanoparticles in antimicrobial therapy

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ABSTRACT

Nanotechnology is expected to open some new aspects to fight and prevent diseases using atomic scale tailoring of materials. The ability to uncover the structure and function of bio systems at the nanoscale, stimulates research leading to improvement in biology, biotechnology, medicine and healthcare. The size of nanomaterials is similar to that of most biological molecules and structures; therefore, nanomaterials can be useful for both in vivo and in vitro biomedical research and applications. The integration of nanomaterials with biology has led to the development of diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles. In all the nanomaterials with antibacterial properties, metallic nanoparticles are the best. Nanoparticles increase chemical activity due to crystallographic surface structure with their large surface to volume ratio.

The importance of bactericidal nanomaterials study is because of the increase in new resistant strains of bacteria against most potent antibiotics. This has promoted research in the well known activity of silver ions and silver-based compounds, including Cu, Ag, Zn, Cd and Ni nanoparticles. This effect was size and dose dependent and was more pronounced against gram-negative bacteria than gram-positive organisms. Also, Biosynthesis of nanoparticles is under exploration is due to wide biomedical applications and research interest in nanotechnology. The biological approach for the synthesis of nanoparticles is considered as more eco-friendly and cost effective as compared to the other chemical and physical approaches. This review detailed view about the Nanostructures antimicrobial Therapy of metal nanoparticles.

Keywords: *Nano Materials; Electron Microscopy; Microstructuremetallic Nanoparticles And Nanowires.*

1. INTRODUCTION

Nanotechnology is of growing importance in many branches of research because of the opportunity for miniaturization and the interesting properties associated with a small particle size. It is well known that many fundamental properties of nanostructure materials (optical, electrical, mechanical, etc.) can be expressed as a function of their size, composition, and structural order. Meanwhile, nanostructures with different morphologies are nuclear parts of functional nanostructure devices (Caruso, 2001; Li *et al.*., 2005). The preparation of nanoparticles is a complicated process and a wide variety of different variables may affect the properties of the final product. Some important variables have distinct effects on the properties of the final product, while others may have only minor effects or no effect at all. Certain variables can also have an interaction effect on the properties of the prepared nanoparticles.

The effects of a large number of variables can be effectively studied with the aid of a statistical experimental design. Their uniqueness arises specifically from higher surface to volume ratios and an increased percentage of atoms at the grain boundaries. The ongoing worldwide nanotechnology revolution is predicted to impact several areas of biomedical research and other science and engineering applications. Nanoparticle assisted drug delivery, cell imaging, and cancer therapy are important biomedical applications of nanotechnology.

For semiconductor materials, doping with different elements can adjust their electrical, optical, and magnetic properties effectively (Li *et al.*., 2005; Chen *et al.*., 2005; Liu *et al.*., 2005; Shen *et al.*., 2005; Yoo *et al.*., 2002; Geng *et al.*., 2003). Progress in utilizing inorganic nanoparticles for biomedical applications has advanced rapidly as a result of the extensive amount of work done in the synthesis and modification of the nanoparticles. The advantage of using the inorganic oxides for biomedical applications is that they contain mineral elements essential to humans and exhibit strong activity even when administered in small amounts. The synthesis of nanorods, nanowires, and nanotubes has generated much interest in recent years with respect to the advanced nanoscience and nanotechnology in the next generation of electronic and optical Nano devices.

Recently, the nanoscience development has been beyond the simple pursuit for single nanoparticle and the hierarchical assembly of nanoscale of building blocks into complex architectures has attracted much interest due to their special collective properties and wide potential applications in functional nano devices. Microbial contamination is a serious issue in health care and food industry, so that development of antimicrobial agents and surface coatings has been attracting increasing attention in recent years. Due to the spread of antibiotic resistant infections, interest in alternative antimicrobial agents, such as inorganic materials, has been rising (Wang *et al.*., 2006).

Antimicrobial properties have been demonstrated for metallic nanoparticles (Wang *et al.*., 2006; Seo *et al.*., 2006) and metal oxide powders and nanoparticles (Dagdeviren *et al.*., 2013). The inorganic materials can be used in different forms, such as powders (Dagdeviren *et al.*., 2013; Samat *et al.*., 2013), coated on cellulose fibers (Wang *et al.*., 2006), or as a part of organic/inorganic nano composite coating. Nanomaterials reveal good result than other techniques used in water treatment because of its high surface area (surface/volume ratio). It is suggested that these may be used in future at large scale water purification (Dhermendra *et al.*., 2008). Silver is a safe and effective anti-bactericidal metal because it is non-toxic to animal cells and highly toxic to bacteria such as Escherichia coli (E. coli) and Staphylococcus aureus, Staphylococcus epidermidis (Michael *et al.*., 2012).

Metal nanoparticles with antimicrobial activity when embedded and coated to surfaces can find immense applications in water treatment, synthetic textiles, biomedical and surgical devices, food processing and packaging (Amant *et al.*., 2012; Gutierrez *et al.*., 2010; Abbott *et al.*., 2007).

2. PROPERTIES OF NANOPARTICLES

Nanomaterials reveal good result than other techniques used in water treatment because of its high surface area (surface/volume ratio). It is suggested that these may be used in future at large scale water purification (Chorianopoulos *et al.*., 2011). Silver is a safe and effective anti-bactericidal metal because it is non-toxic to animal cells and highly toxic to bacteria such as Escherichia coli (E. coli) and Staphylococcus aureus, Staphylococcus epidermidis (Fujishima *et al.*., 1972). Metal nanoparticles with antimicrobial activity when embedded and coated to surfaces can find immense applications in water treatment, synthetic textiles, biomedical and surgical devices, food processing and packaging (Fujishima *et al.*., 1972; Wei *et al.*., 1992; Pham *et al.*., 1995). Recently, the eco-toxicity of transition metal oxide nanoparticles (NPs) from their unique behaviors in natural environments has attracted great attention. The eco-toxicity for nanomaterials is not a new concept. For example, carbon-based nanomaterials (CBNs) have been reported to cause significant cellular damage, which has contributed to their physical and chemical stresses on biological systems, or to light-triggered free radicals. Furthermore, transition metal oxide NPs may cause even higher environmental concerns because of their unique dissolution properties, electronic charges, small size and large surface-to-mass ratio. The electronic structures of transition metal oxides have attracted much attention by chemists and physicists. Some transition metal oxides are semiconductors, which can play as photo-catalysts for degradation of organic and inorganic pollutants. Similarly, they can be used to kill the bacteria with their photocatalytic properties. Taking TiO_2 as an example, when TiO_2 NPs are irradiated by UV light (wavelength about 380nm), the electron-hole pairs will form, which can 2 trigger a series of redox reactions in biological systems. The electronic structures for semiconductors, in physical perspective, are composed of valence band, conduction band and band gap. Under the UV-light irradiation, the electrons from valence band are excited to the conduction band, which cause the formation of electron-hole pairs. The holes can capture the biological species and oxidize them, while the electrons can trigger reduction reactions. These physical properties have wide applications in industry as well as environmental engineering field. Through last decades, many researchers had focused on the study of eco-toxicity of transition metal oxide NPs with their unique photocatalytic behaviors. As for the fast development of nanotechnology, this kind of research will continue to deepen our understandings of metal nanoparticles' biological functions and to provide potential new applications of these nanoparticles.

Metal nanoparticles are among the most popular types of nanomaterials. Metal nanoparticles like CuO, ZnO, TiO_2, nanosilver, and nanogold have a wide variety of applications, including use in industry, consumer products, medicine, and pesticide products. Copper oxide nanoparticles are used as additives in inks, plastics, lubricants; as coatings for integrated circuits and batteries; and as bactericides for air and liquid filtration. Thus, metal nanoparticles from various sources, including a growing number of pesticide products, could make their way to the surface waters. Unfortunately, little published information exists on the environmental fate of nanometals, including nanocopper. Metal nanoparticles, when added to the water, can aggregate, sediment out of the water column, adsorb to nutrients, and disassociate to release soluble metal ions (Gao *et al.*.,2005).

Indications that both water chemistry and the reactivity of the nanoparticle itself should be considered in environmental speciation studies. Hence, laboratory experiments that use deionized water and artificial methods to suspend nanoparticles may not realistically reflect what occurs in natural environments. The effects of nanocopper on aquatic organisms have not been well studied. Existing studies indicate that copper toxicity strongly depends on particle size. As particle size decreases, toxicity increases. Among the studies that have been performed, there is a 15- to 65-fold increase in toxicity when nano-sized copper particles are used. In most studies, the increase in nanocopper toxicity is attributed to an increase in solubility and, consequently, bioavailability. However, increased solubility does not always explain increased nanocopper toxicity. Copper nanoparticles can induce toxicity by mechanisms that are different from those of soluble ions. When exposed to equivalent bio available amounts of nano and soluble metal forms, gill copper uptake was identical in zebrafish. However, nanocopper caused greater damage to the gill. Nanocopper produced different morphological effects and global gene expression patterns in the gill than did soluble copper ions alone. Similarly, reported that soluble copper ions explained 50% of nanocopper toxicity in yeast. *In vitro* studies provided evidence to show that copper nanoparticles have the ability to cause mitochondrial and DNA damage. Although the mechanisms of nanoparticle toxicity are not well understood, the findings to date suggest that both ionic copper and nanoparticulate copper are responsible for the toxicity that is produced.

The synthesis method will be applied to deliver several types of transition metals (Ti, Mg, Fe, Ni, Cu, Co and Zn) and metal oxides (TiO_2, MgO, Fe_2O_3, NiO, CuO, and ZnO) NPs to microbes for testing their eco-toxicity (Ireland *et al.*., 1668).

3. RESULTS SECTIONPREPARATION OF NANOPARTICLES

Several methods exist for the generation of metal nanoparticles. They can be formed from gas phase processes by nucleation of atoms and molecules from saturated gases. Other techniques include the template based systems, sol-gel and chemical vapor depositions.

Due to small interparticle distances, aggregation of the NPs by vander Waals forces of attraction is virtually unavoidable. To counter this, solution-phase methods involving surfactants are employed to provide stability to the NPs when they are formed. Typically, an aqueous solution of the corresponding metal salt is reduced using sodium citrate or sodium borohydride Other methods that reduce metal NP aggregation involve their generation in a polymer matrix.

The use of thiols as capping agents has also become a common approach to making functionalized metal nanoparticles. In the early 1990s, Mathias Brust and co-workers developed a single- and two- phase procedure for the preparation of thiol-stabilized gold nanoparticles by reduction of hydrogen tetrachloroaurate using sodium borohydride. A similar synthetic procedure has been extended to the preparation of other thiol-functionalized metal NPs like Ag and Cu and is widely known in the literature as the Brust synthesis.

4. NANOPARTICLES AS ANTIMICROBIALS

4.1. Titanium dioxide nanoparticles.

The inhibitory activity of TiO_2 is due to the photocatalytic generation of strong oxidizing power when illuminated with UV light at wavelength of less than 385 nm (Matsunaga *et al.*., 1998). TiO_2 particles catalyze the killing of bacteria on illumination by near-UV light. The generation of active free hydroxyl radicals (OH) by photoexcited TiO_2 particles is probably responsible for the antibacterial activity (Matsunaga *et al.*., 1988). The antimicrobial effect of TiO_2 photocatalyst on Escherichia coli in water and its photocatalytic activity against fungi and bacteria has been demonstrated (Kim *et al.*., 2003). There are also studies on bactericidal activity of nitrogen-doped metal oxide nanocatalysts on E. coli biofilms and on the photocatalytic oxidation of biofilm components on TiO_2- coated surfaces (Chawengkijwanich *et al.*., 2008). In conclusion, the use of TiO_2 photocatalysts as alternative means of self-disinfecting contaminated surfaces by further development may provide potent disinfecting solutions for prevention of biofilm formation. TiO_2 photocatalysts can be used as effective biofilm disinfectant in food processing industries (Liu *et al.*., 2007). Suspensions containing TiO_2 are effective at killing Escherichia coli. This has led to the development of photocatalytic methods for the killing of bacteria and viruses using TiO_2 in aqueous media. It has been suggested that nanostructured TiO_2 on UV irradiation can be used as an effective way to reduce the disinfection time, eliminating pathogenic microorganisms in food contact surfaces and enhance food safety (Wolfrum *et al.*., 2002). The major disadvantage of using TiO_2 is that UV light is required to activate the photocatalyst and initiate the killing of the bacteria and viruses. In recent years, visible light absorbing photocatalysts with Ag/AgBr/TiO_2 has proved to be successful at killing S. aureus and E. coli (Saito *et al.*., 1992).

4.2. Magnesium oxide nanoparticles.

Highly ionic nanoparticulate metal oxides can be prepared with extremely high surface areas and unusual crystal morphologies having numerous edge/corner and reactive surface sites (Duffy *et al.*., 2002). Magnesium oxide (MgO) prepared through an aerogel procedure (AP-MgO) yields square and polyhedral shaped nanoparticles with diameters varying slightly around 4 nm, arranged in an extensive porous structure with considerable pore volume (Sunada *et al.*., 1998). An interesting property of AP-MgO nanoparticles is their ability to adsorb and retain for a long time (in the order of months) significant amounts of elemental chlorine and bromine (Hu *et al.*., 2006). The AP-MgO/X_2 nanoparticles exhibited biocidal activity against certain vegetative Gram-positive bacteria, Gram-negative bacteria and the spores (Klabunde *et al.*., 1996). AP-MgO nanoparticles are found to possess many properties that are desirable for a potent disinfectant (Richards *et al.*., 2000). Because of their high surface area and enhanced surface reactivity, the nanocrystals adsorb and carry a high load of active halogens. Their extremely small size allows many particles to cover the bacteria cells to a high extent and bring halogen in an active form in high concentration in proximity to the cell. Standard bacteriological tests have shown excellent activity against E.coli and Bacillus megaterium and a good activity against spores of Bacillus subtilis (Koper *et al.*., 2002). The bioactivity of AP-MgO/X_2 nanoparticles is due to the positive charge they have in water suspension, opposite to those of the bacteria and spore cells, which enhances the total bactericidal effect. Confocal microscopy studies have shown that in water suspension the opposite charge brings the bacteria and nanoparticles together in aggregates composed of both AP-MgO nanoparticles and bacteria. Atomic force microscopy and electron microscopy studies demonstrate that halogenated magnesium oxide has a very strong influence on microorganisms and their membranes in particular. Overall, the halogen such as chlorine and bromine treated MgO nanoparticles have a stronger and faster effect on the killing action of both bacteria and spores (Richards *et al.*., 2000).

4.3. Iron oxide nanoparticle.

Iron oxide nanoparticles were synthesized by cost effective co-precipitation method. It possesses strong ferromagnetic behavior and less sensitivity to oxidation. Iron oxide nanoparticles have attracted much interest because they belong to the class of materials having non-toxicity and biological compatibility due to the presence of Fe (II/III) ions (Liu *et al.*., 2008).

Due to its 4 unpaired electrons in 3d shell, an iron atom has a strong magnetic moment. Ions Fe^{2+} has also 4 unpaired electrons in 3d shell and Fe^{3+} has 5 unpaired electrons in 3d shell. Therefore, when crystals are formed from iron atoms or ions Fe^{2+} and Fe^{3+} they can be in ferromagnetic, antiferromagnetic or ferromagnetic states (Massmart*et al.*., 1981).

This study focuses on the investigation of the antimicrobial behavior of iron oxide nanoparticles (IO-NPs) prepared by an adapted co-precipitation method (Predoi *et al.*., 2007) and on the analysis of M-H hysteresis loops at room temperature.

Transmission electron microscopy studies have been conducted to obtain information about size, structure and morphology of the fabricated IO-NPs. he antimicrobial activity of the IONPs was investigated by qualitative and quantitative assays and their cytotoxic effect was assessed on HeLa cells.

In this study, the IO-NPs were tested in aqueous suspension against a large spectrum of microbial strains, both by antimicrobial susceptibility standard methods (agar diffusion and minimal inhibitory concentration assay) as well as by methods aimed to investigate the efficiency of IO-NPs against bedded cells, which are much more resistant to different stress factors, including antimicrobials, than their plank tonic counterparts.

The antimicrobial activity of the IO-NPs has been studied on strains belonging to common bacterial pathogens, that is, the Gram-negative, P. aeruginosa, E. coli, Gram-positive E. faecalis, B. subtilis, and a yeast strain of C. krusei. After the qualitative screening, the microbial strains which proved to be susceptible to the tested nanoparticles have been investigated in the quantitative assay for establishing the MIC value. he highest tested concentration was of 5mg/mL, because at higher concentrations, the colored iron oxide suspension would have interfered with the reading growth especially at high concentrations.

He stimulatory effect of iron oxide nanoparticles on the microbial growth was also reported by other authors, that is, on E. coli (Predoi *et al.*., 2007) or E. coli, P. aeruginosa and E. faecalis, C. albicans (Zins *et al.*., 1999). Hence results could be explained by the ability of the microbial strains to use the iron oxide as a metabolic source of iron, which is known to positively regulate the microbial growth rate and other physiological processes (Cava *et al.*., 1990). On the other hand, these nanoparticles could be used for targeted transport of an antimicrobial agent and its subsequent removal by means of an external magnetic field.

4.4. Copper Nanoparticles.

A copper nanoparticle, due to their unique physical and chemical properties and low cost preparation, is of great interest today. Copper nanoparticles have great applications as heat transfer systems, antimicrobial materials, super strong materials, sensors, and catalysts. Copper nanoparticles can easily oxidize to form copper oxide.

If the application requires the copper nanoparticles to be protected from oxidation, the copper NPs are usually encapsulated in organic or inorganic material such as carbon, silica. Some of the copper nanoparticles applications are discussed below. Copper nanoparticles due to their high surface to volume ratio are very reactive, can easily interact with other particles and increase their antimicrobial efficiency.

Colloidal copper has been used as an antimicrobial agent for decades. Copper nanoparticles (about 6nm) embedded in polyvinyl methyl ketone films exhibit a noticeable inhibitory effect on the growth of microorganisms (E.coli and S.cerevisiae), Due to the stability of copper nanoparticles supported on a matrix, and their disinfecting properties, copper nanoparticles can be used in paint or plaster as a bactericidal agent to coat hospital equipment. Metallic nanoparticles can be used in heat transfer systems to improve efficiency.

Conventional heat transfer fluids have poor heat transfer properties. Fluids containing metallic nanoparticles with a thermal conductivity of about three times that of a pure fluid could double the fluid’s heat transfer rate. It is reported that adding only 0.3 volume percent of copper nanoparticles, with average diameter of less than 10 nm, to ethylene glycol increases its thermal conductivity up to 40%,37 A major problem facing fuel cell technologies is formation of high levels of carbon monoxide (CO) which is produced during hydrogen production. One way to eliminate the CO by product is to combine it with water to produce hydrogen gas and carbon dioxide (CO_2) in a process known as the “water gas shift” reaction (See reaction below).

$$CO + H_2O \longrightarrow H_2 + CO_2$$

With the assistance of proper catalysts, the water shift reaction can convert a large portion of carbon monoxide into carbon dioxide. For this purpose, nanoparticles of either gold or copper supported on a metal oxide (zinc oxide, ZnO and cerium oxide, CeO2) is used. In particular, it was found that the greatest catalytic activity is achieved with extremely small copper or gold nanoparticles less than 4 nm (2-4 nm) supported on the metal cerium oxide. Although, gold nanoparticles show the greatest catalytic activity in water-gas shift reaction, copper is also equally reactive, and its cost is much lower (Dinesh *et al.*., 2013).

4.5. Copper oxide nanoparticles.

Copper oxide (CuO) is a semiconducting compound with a monoclinic structure. It is the simplest member of the family of copper compounds and exhibits a range of potentially useful physical properties such as high temperature, superconductivity, electron correlation effects and spin dynamics.

Therefore, it finds a wide application (Dinesh *et al.*., 2013; Dinesh *et al.*., 2014). CuO crystal also has photocatalytic or photovoltaic properties and photoconductive functionalities. There is limited information available about the antimicrobial activity of nano CuO. As CuO is cheaper than silver, easily mixes with polymers and relatively stable in terms of both chemical and physical properties, it finds a wide application (Tranquada *et al.*., 1995). It is suggested that highly ionic nanoparticulate metal oxides, such as CuO, may find potential application as antimicrobial agents as they can be prepared with extremely high surface areas and unusual crystal morphologies (Kwak *et al.*., 2005). CuO nanoparticles were effective in killing a range of bacterial pathogens involved in hospital-acquired infections. But a high concentration of nano CuO is required to achieve a bactericidal effect (Xu *et al.*., 1999). It has been suggested that the reduced amount of negatively charged peptidoglycans makes Gram-negative bacteria such as Pseudomonas aeruginosa and

Proteus spp. less susceptible to such positively charged antimicrobials.

Copper nanoparticles have a high antimicrobial activity against B. subtilis. This may be attributed to greater abundance of amines and carboxyl groups on cell surface of B. subtilis and greater affinity of copper towards these groups. Copper ions released may also interact with DNA molecules and intercalate with nucleic acid strands. Copper ions inside bacterial cells also disrupt biochemical processes. The exact mechanism behind bactericidal effect of copper nanoparticles is not clear.

4.6. Zinc oxide nanoparticles.

Among the various metal oxides studied for their antibacterial activity, zinc oxide nanoparticles have been found to be highly toxic. Moreover, their stability under harsh processing conditions and relatively low toxicity combined with the potent antimicrobial properties favors their application as antimicrobials (Ren *et al.*., 2009). Many studies have shown that some NPs made of metal oxides, such as ZnO NP, have selective toxicity to bacteria and only exhibit minimal effect on human cells, which recommend their prospective uses in agricultural and food industries. The antimicrobial activity of zinc oxide nanoparticles have been studied against the food related bacteria Bacillus subtilis, Escherichia coli and Pseudomonas fluorescens. ZnO NP could potentially be used as an effective antibacterial agent to protect agricultural and food safety from foodborne pathogens, especially E. coli O157:H7. ZnO NPs possess antimicrobial activities against Listeria monocytogenes, Salmonella enteritidis and E. coli O157:H7 in culture media. There are also other studies confirming the strong antimicrobial activity of ZnO nanoparticles wherein the nanoparticles could completely lyse the food-borne bacteria Salmonella typhimurium and Staphylococcus aureus. In another study, ZnO nanoparticles (12 nm) inhibited the growth of E. coli by disintegrating the cell membrane and increasing the membrane permeability. The above findings suggest that ZnO nanoparticles can find applications in food systems and can be used to inhibit growth of pathogenic bacteria. There are several mechanisms which have been proposed to explain the antibacterial activity of ZnO nanoparticles. The generation of hydrogen peroxide from the surface of ZnO is considered as an effective mean for the inhibition of bacterial growth. It is presumed that with decreasing particle size, the number of ZnO powder particles per unit volume of powder slurry increases resulting in increased surface area and increased generation of hydrogen peroxide. Another possible mechanism for ZnO antibacterial activity is the release of Zn2+ ions which can the damage cell membrane and interact with intracellular contents.

Nano materials are the leading in the field of nano medicine bionanotechnology and in that respect nanotoxicology research is gain in great importance. The US Environmental protection agency (EPA) as approved registration of copper as on antimicrobial agent which is able to reduce specific harmful bacteria linked to potentially deadly microbial infections (European Copper Institute). In addition no research as discovered any bacteria able to develop immunity to copper as they often do with antibiotics. The emergence of nanoscience and nanotechnology in the last decade presents opportunities for exploring the bacterial effect of the metal nanoparticles. The bacterial effect of the metal nanoparticles has been attributed to their small size and high surface volume to ratio, which allows them to interact closely with microbial membranes and is not merely due to the release of metal ions in solution.

A cell wall is present around the outside of the bacterial cell membrane and it is essential to the survival of bacteria. It is made from polysaccharides and peptides named peptidoglycon. There are broadly speaking two different types of cell wall in bacterial, called gram-positive and gram-negative. The names originate from the reaction of cells to the gram stain, a test long-employed for the classification of bacterial species. Gram-positive bacteria possess a thick cell wall containing many layers of peptidoglycon. In contrast, gram-negative bacteria have a relatively thin cell wall consisting of a few layers of peptidoglycon. Surfaces of copper nanoparticles affect interact directly with the bacterial outer membrane, causing the membrane to rupture and killing bacteria [55].

5. APPLICATION OF NANOPARTICLES

It is evident that the metal based nanoparticles constitute an effective antimicrobial agent against common pathogenic microorganisms. Therefore, some of the nanoparticles such as silver, titanium dioxide and zinc oxide are receiving considerable attention as antimicrobials and additives in consumer, health-related and industrial products. As silver nanoparticles have a broad spectrum antimicrobial activity against several pathogens they are increasingly incorporated into various matrices to extend their utility in materials and biomedical applications (Rupareli *et al.*., 2008).

They are used as additives in health related products such as bandages, catheters, and other materials to prevent infection, particularly during the healing of wounds and burns. An antibacterial Ag/Na carboxymethyl cotton burn dressing by the partial cation exchange of sodium with silver has been developed and these can find applications in surgical dressings. They are currently being added to many common household products such as bedding, washers, water purification systems, tooth paste, shampoo, fabrics, deodorants, filters, paints, kitchen utensils, toys, and humidifiers to impart antimicrobial properties (Sadiq *et al.*., 2009). Nanoparticles of titanium dioxide are used in cosmetics, filters that exhibit strong germicidal properties and remove odors, and in conjunction with silver as an antimicrobial agent.

Moreover, due to the photocatalytic activity, it has been used in waste water treatment. It is considered non-toxic and has been approved by the American Food and Drug Administration (FDA) for use in human food, drugs, cosmetics and food contact materials.

Nowadays titanium dioxide nanoparticles are finding wide application as a self-cleaning and self-disinfecting material for surface coatings in many applications and in food industries for disinfecting equipments. Zinc oxide (ZnO) and copper oxide nanomaterials due to their antimicrobial property are being incorporated into a variety of medical and skin coatings. ZnO nanoparticles are used in the wallpapers in hospitals as antimicrobials. ZnO powder is an active ingredient for dermatological applications in creams, lotions and ointments on account of its antibacterial properties. It is evident that metal based nanoparticles due to their biological and physiochemical properties are promising as antimicrobials and therapeutic agents. They can be used to address a number of challenges in the field of nanomedicine. But it must be remembered that they can also possibly cause adverse biological effects at the cellular and subcellular levels. Therefore, after the cytotoxicity and clinical studies the nanoparticles can find immense application as antimicrobials in the consumer and industrial products.

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7. CONFLICTS OF INTEREST

The authors declare no conflict of interest.