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Titania Nanoparticles: An Efficient Antimicrobial Agent

1Purvi B Shukla
1ASSISTANT PROFESSOR
1GTU

Abstract:
Multidrug resistance developed by many microorganisms lead to search for the novel remedy to treat pathogens. Many metals and metal oxide nanoparticles such as silver, zinc oxide, copper, copper oxide and titanium dioxide demonstrated antimicrobial properties since ancient times. Nano particles of titanium dioxide find applications in the field of catalysis, cosmetics, medicines, paints, coatings, solar devices etc. In this review, the antimicrobial properties of TiO2 nanoparticles synthesized by chemical and green route are summarized. TiO2 nanoparticles found to be potential antimicrobial agents against gram positive and gram negative bacteria. These nano particles are widely used in the field of dentistry to treat infections caused by Streptococcus mutans commonly found pathogen in oral cavity. In the field of food packaging these nanoparticles are effective against Escherichia coli. TiO2 nano particles act via release of anti oxidatns that cause damage to microbial cells. TiO2 nanoparticles in various forms i.e nanoparticles suspension, colloidal form, coatings or incorporated in fabric are effective against microorganisms. Titanium dioxide nano particles are low cost, non toxic , stable and effective against microorganisms. They are widely used in the field of medicine, textile and food packaging.

Key words: Titanium dioxide, nano particles, Escherichia Coli, Streptococcus mutans, Anti microbial

INTRODUCTION:

At world level antibiotic resistance is developing dangerously high. Numerous microorganisms have developed resistance towards the drugs that are designed to kill them and therefore the drug become ineffective towards microbes spreading infections. These infections leads to extended hospital stays, the infected must opt for costly and toxic alternatives and doctor visits. Drug resistance occurs in all most all areas such as agriculture ,veterinary and human health. People with chronic diseases are most difficult to treat when bacteria develop drug resistance. Innovation of newer technologies must be encouraged to deal with the problem. Maintaining a very good hygiene is the key to prevent bacterial infection. Many other methods such as Antimicrobial peptides, bacteriophages, antibacterial oligonucleotides or nano particles are used to deal with life threatening bacterial infections. Metal, metal oxide or alloy nano particles are frequently used to kill microorganisms. Copper, Zinc, silver and titanium metal oxides are effective against broad spectrum of microbes. Metal oxide nano particles offers the advantage of stability, low cost, non toxic and powerful action. . TiO2 nano particles are antimicrobial due to their strong oxidizing power by free radical generation. Titanium dioxide nano particles either alone or in combined form (doped or composite) are used in field of photo catalysis, food packaging, cosmetics, paint, textile and medicine to inhibit microbial growth

REVIEW OF LITERATURE:

When comes in contact with microorganisms present on various surfaces in air and water, photosynthesized TiO2 acts as bactericidal by releasing ROS(reactive oxygen species). This mechanism of action is the efficient way of preventing diseases.[1] Glass surfaces were coated with TiO2 syhtesized by sol-gel method and then exposed to source of light. Anti microbial action was determined by count reduction test against Bacillus atrophaeus, Aspergillus niger and Kocuria rhizophil. These nano particles showed promising results.[2] Three antibacterial photo induced (UV-irradiated) materials Nano structured TiO2 films, nano particles of TiO2 and TiO2-silica were checked against Escherichia coli and Bacillus subtili. These materials generated radical species that caused oxidation and inactivation of bacterial cells.[3] A comparison of antimicrobial activity of nano particles was done for zeolite supported Zinc oxide, TiO2 and TiO2/ZnO. Test microorganisms selected were gram positive and gram negative bacteria. Anti microbial behaviour of synthesized material depends on type of nano particles and selected bacterial species. From the experiments of minimum Inhibitory Concentration MIC90 (2mg/ml), minimum bactericidal concentration MBC (2mg/ml) and Fractional Inhibitory concentration FIC (0.25mg/ml),E.Coli bacteria were found to be the most affected among S. aureus,P. fluorescens and L. Monocytogenes. The Zeolite supported materials showed sustained release of nano particles with increased inhibition and these materials may be used in food packing .[4] Multidrug resistance development by many bacterial species lead to innovation of new anti microbial materials. Many metal oxide nano particles show excellent fungicidial and bactericidal properties against both gram positive and gram negative microorganisms. Nano particles possess strong oxidizing power due to free radical generation that inhibits growth of microorganisms. Titanium dioxide nanoparticles are low cost , non toxic and chemically stable.[5] Hollow calcined TiO2 nanospheres were prepared by electrospinning and atomic layer deposition method. Characterization was done using X ray diffraction , FTIR and thermogravimetric analysis. Antimicrobial activity of these nano sphere was determined against S. aureus and E. coli strains. The results were promising in case of CSTiO2 as compared with commercial TiO2.[6] Silver doped titanium dioxide and copper doped titanium dioxide were synthesized via environmentally friendly route. Their bactericidal activity was determined for E. coli C600 and S. cerevisiae W303 strains. Various conditions such as radiated and non radiated, and different time intervals chosen for determination. These materials released silver and Cu+ metal ions in solution. Photo activated Ag-TiO2 showed powerful antimicrobial action against E.Coli as compared to Cu-TiO2 .When these materials at various concentrations tested for plants anti microbial action was observed without affecting growth and germination of plant.[7] Photo activated titanium dioxide nanoparticles find its potential in the field of water and air pollution control. TiO2 nano particles synthesized by sol-gel method using solar energy are found to be effective against common pathogenic microorganisms such as Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus and Klebsiella pneumoniae under the effect of UV and visible light. [8] TiO2 nano particles showed potential in food packing industries. These nano particles coated on low density polyethylene film used for packaging found to be effective against Escherichia coli under the conditions of UV and fluorescent light and at different time intervals. Antimicrobial activity enhanced in case of UV light exposure and as concetration of TiO2 increased. This coated film has the potential to increase shelf life and maintain the quality of packaged food.[9] Nano particles of silica, silver and titanium dioxide were checked for their bactericidal action in dentistry against the oral pathogenic species of Streptococcus mutans. Determination was done by measurements of lactate, fluorescent staining and minimum inhibitory concentration. TiO2 nano particles at 100 mg/ l concentration could inhibit complete microbial growth.[10] Reactive oxygen species generated by UV light exposed photocatalytic TiO2 nano particles have the capacity to destroy many organic molecules. TiO2 nanoparticels are used for water treatment and sterilization of many surfaces. When used along with potassium Iodide, TiO2 could inhibit growth of gram-positive , gram-negative bacteria and fungi .The anti microbial action depended on the influence of UVA light, the concentration of TiO2 and the concentration of KI. The bactericidal action was due to long lived hypoiodite and iodine.[11] Nano colloids of TiO2 were prepared by sono chemical method. Characterization was done by SEM, XRD and EDX. Nano particles are found to be of uniform morphology, tetragonal structure and spherical nature. These nano particles when checked for gram positive and gram negative bacteria, showed maximum effect against Pseudomonas aeruginosa with MIC ($67.3 \pm 2.5\%$) at 150 μg ml^{-} dose. Mechanism of action is probably damage to the lipids in viral envelop. The result shows potential application of this material in poultry.[12] In the field of sanitary and medicine TiO2 nanoparticles play a wide role. Photocatalytic TiO2(UV irradiated) nanoparticles were incorporated in

polypropelene and checked by methylene blue testing against Escherichia coli bacteria. The photo catalytic and antimicrobial activity increased with increasing concentration of TiO2 which caused surface change with bactericidal effect.[13] Multi drug resistance developed by many microorganisms lead to search for new drug. Metal nanopraticles such as copper, silver, zinc oxide etc. show antimicrobial behaviour with the advantage of stability, low cost and bio safety. These nano partilces irradiated with ultra violet radiation (> 387 nm) have the auto anti bacterial function in the visible range also.[14] Heterogeneous catalyst photo induced titanium dioxide was used as coating material on biomedical devices due to its self sterilizing properties. A huge no. of titanium alloys are also used for making biomedical devices. From X ray diffraction and Infra red studies it is known that irradiated TiO2 produced reactive oxygen species and there is direct damage of bacterial cell due to direct oxidation or lipid peroxidation.[15] Reactive oxygen species responsible for bacteria killing are produced by TiO2 due to visible light excitation. Titanium dioxide when combined with carbon nano tubes or graphene sheets, enhanced biocompatibility and anti bacterial activity of material and used in orthopedic implants. Incorporation of titanium dioxide, copper doped TiO2 in chitosan or textile matrix gives enhanced antimicrobial property to the resulting material against Staphylococcus aureus and Escherichia coli.[16] Titanium dioxide nano particles are synthesized via green route from Mentha arvensis leaf extract and titanium tetra isopropoxide precursor. XRD data confirmed crystalline structure of nano particles and SEM data revealed spherical structure of nano particles with excellent antifungal and anti bacterial activity against targeted microorganisms.[17] Photoactivated TiO_2 nano particles were synthesized by sol gel method and applied on the glass slides. Antimicrobial efficiency of this material was checked against vegetative microorganisms like Bacillus atrophaeus, Aspergillus niger, Kocuria rhizophila with different parameters such as inoculation density, relative humidity and intensity of radiation. In all mentioned conditions titanium dioxide coated glass surface showed promising results.[18] Antimicrobial action of nano structured titanium film, titanium dioxide nano particles and TIO2-silica aerogel was estimated for inactivation of Escherichia Coli and Bacillus subtilis. It was found that when the material was UV radiated , released radical species that caused oxidation and inactivation of microbial cells.[19] The beta-lactamases producing bacteria such as Pseudomonas aeruginosa, Escherichia coli and Klebsiella pneumoniae were chosen as test microorganisms for titania nano particles. Results of Disc diffusion method showed highest zone of inhibition between 20 and 25 mm for K. pneumoniae at MIC 1.2mg/ml and 1.4mg/ml.[20] Laser ablation was done to synthesize colloidal solution of 36 nm TiO2 nano particles both in distilled water and in alcohol.This colloidal solution was checked against Staph. and E.coli bacteria. The MIC in distilled water for E.coli was 9.45 mg/l and for Staph. was 18.91mg/l. In alcohol MIC for E.coli was4.7 mg/l and for Staph. was 9.45 mg/l. [21] Due to Osteoconductivity & high biocompatibility TiO2 nano tubes was selected as scaffolding material in large bone defects.[22] As quaternary ammonium salts are known for their powerful antimicrobial action, quaternary ammonium salt of titanium dioxide nano particles were synthesized and tested against E.Coli. 99.99% inhibition was observed within 10 minutes when bacteria mixed with nano particles. This property of quaternaty ammonium salt of TiO2 make them potential agent in treatment of waste water and to be used as self cleaning surfaces.[23] Titanium dioxide and TiO2/Ag nanoparticles were synthesized by microwave assisted hydro thermal process and used as anti biofilm filler content. Both the materials were tested against Streptococcus mutans for antimicrobial potential. TiO2/Ag NPs remarkably reduced ($p < 0.05$) the biofilm accumulation of S. mutans on the composite resin surface.[24] Silicone rubber composites were made using UV radiated TiO2 nano particles and tested against Escherichia coli. Antibacterial sensitivity test showed thousand times decrease of CFU after 2 hours exposure of light. The reactive oxygen species generated by light exposure is responsible for the bactericidal action. [25] A biodegradable , highly homogeneous , soft Composite was prepared using starch, titanium dioxide and /or vancomysin antibiotic. Standard tube dilution test and disc diffusion test were done for bacteriostatic characteristics of composite agianst CCM 4223 Staphylococcus aureus. This composite can be effectively used for local release antibiotics.[26] To prevent the infections in artificial joints silver containing titanium dioxide capsules were developed. These capsules were found to be effective against E.coli and S.aures bacteria without disturbing cell viability at doses upto 20 µg/ml making the artificial implant coating fit for biomedical use.[27] Non-cytotoxic Ag-TiO2 nanoparticles when used in footwear industry could inhibit fungal infections due to poor breathability or promoted by humidity[28] An economical biosyntheis of oval shaped titanium dioxide nano particles from Cowpea seed extract was done and tested against clinical pathogens. It was observed that these nanoparticles were effective against majority of the

pathogens due to their antioxidant nature. They showed cytotoxicity on MG63 osteosarcoma cell lines. These low cost nano particles can further be used in treatment of various types of cancer.[29] Nitrogen doped titanium dioxide nanoparticles were synthesized, used in orthdontic brackets and wires and evaluated upto 90 days against Strptococcus mutans for their anti microbial efficacy. Effectiveness of these nano particles was proved in preventing enamel decalcification.[30] Titanium dioxide nano particles found to be useful antibacterial material in textile industries also. TiO2 nanoparticles either introduced into the fibre or deposited on to the fibre (polyester material) demonstrated almost similar behaviour against Klebsiella pneumoniae and Staphylococcus aureus without changing appearance of the cloth. Anti bacterial property was retained after washing also.[31] Streptococcus mutans is the common pathogen found in the oral cavity. Nano particles of TiO2 s are economical with extraordinary mechanical properties and good color. 1% TiO2 nanoparticles (w/w) could significantly reduce bacterial growth.[32] S. mutans and S. sanguinis are commonly found challenging microorganisms in practice of dentistry. TiO2 is found to be a good anticaries agent due to its photocatalytic characteristics. [33] Solvent play a major role in deciding shape, stability and reactivity of synthesized nano particles. Sol-gel method was used to prepare titanium dioxide nano particles with various solvents such as , acetic acid, diethanolamine and propionic acid. Nano particles possessed spherical shape with average particle ssize 10-68 nm. Very good anti microbial activity was determined at 250 mg/mL by agar wall diffusion method against Pseudomonas aeruginosa and Escherichia coli. [34] Staphylococcus aureus bacteria mediated low cost, green synthesis was done for TiO2 nano particles with average diameter of 20nm and spherical shape. Results of Disc diffusion method demonstrated Gram-negative bacteria are more affected than Gram-positive bacteria. To avoid pathogenic infections TiO2 NPs can be utilized in coating the medical devices.[35] Ag doped titania incorporated into epoxy resin and checked for bactericidal effect against S. mutans. Results of UV-VIS spectrophotometry showed nano particles(>2%wt) were capable to show an extraordinary bactericidal effect when in contact with S. mutans under visible light.[36] TiO2 nano particles incorporated into various fabrics and tested against Klebseilla pneumoniae and S.aureus microorganisms. These nanoparticles showed considerable reduction against bacteria without compromising fabric properties such as tensile strength, wrinkle recovery and air permeability as compared to untreated fabric.[37] A comparison of bactericidal properties was done between chemically synthesized and biologically prepared(Pithecellobium dulce and Lagenaria siceraria leaf extract) TiO2 nano particles against B. subtilis. Biologically prepared nanoparticles released free radiclas and were having good dispersibility, stability and antimicrobial property.[38]

FINDINGS & SUGGESTIONS:

TiO2 nano particles either synthesized by chemical method or via green synthesis exhibited very good anti microbial action against majority of gram positive as well as gram negative microorganisms. Photo activated titanium dioxide nano particles react by releasing anti oxidants that cause damage to bacterial cell. Due to their antimicrobial properties, TiO2 nano particles are used in water treatment, food packaging, textile, polymers, implants and as coatings on various surfaces.

CONCLUSION:

TiO2 nano particles are non toxic, stable, low cost and bio safe. They show powerful anti bacterial effect against wide spectrum of microorganisms. These nano particles find their application in almost all fields pertaining to health and hygiene.

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