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The applications of GNPs and SNPs in medical implant

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Abstract. Nanomaterials have been widely utilized in medical implant. This review demonstrates a number of applications of GNPs (gold nanoparticles) and SNPs (silver nanoparticles) in medical implants, including three main aspects, which are dentistry, orthopaedics and soft tissue. Nanomaterials are also known as ultrafine particle materials. Nanomaterials are composed of particles with a size range of 1 ~ 100nm. They are usually in the transition region of the interface between atomic clusters and macroscopic objects. Subsequently, the differences and identities between the applications of two sorts of nanoparticles are compared, along with advantages and limits accordingly and respectively. GNPs are more utilized according to their stability, biocompatibility, coordination functions and promotion mechanism in the human body, while SNPs are more used according to, most significantly antibacterial properties, biocompatibility and coordination functions. And this may path pave the way for those who need to generally decide which nanoparticle is more suitable when it comes to a certain field of medical implant.

Keywords: Gold Nanoparticles, Silver Nanoparticles, Medical Implant.

1. Introduction

Nanomaterials are also known as ultrafine particle materials. Nanomaterials are composed of particles with a size range of 1 ~ 100 nm. In the transition region of the interface between atomic clusters and macroscopic objects, nanomaterials have a surface effect, small size effect and macroscopic quantum tunneling effect, which makes the properties of nanomaterials in optical, thermal, electrical, magnetic, mechanical and chemical aspects significantly different from those of large-particle solid materials. There are several methods to prepare gold nanoparticles, which are utilized widely. In physical preparations, the vacuum evaporation method and high-energy ball milling method are the most popular. The vacuum evaporation method is that, in the vacuum chamber, the raw material to be formed into a film is heated in the evaporation container, so that its atoms or molecules are vaporized from the surface to escape, forming steam into the substrate or substrate surface, and condensing to form a film. The high-energy ball milling method is to put the material into the air mill or high-energy ball mill, the material and the medium grind each other, the impact makes the material thinner, the product is granular, the shape is irregular, the surface is easy to react with the medium and be polluted, the particles due to multiple crushing, deformation, cold welding and so on produce a large number of defects. The surface has many holes and active poles. In chemical preparations, there are numerous methods, such as the sodium citrate reduction method, oxalic acid reduction method, etc., but their universal principles are mainly utilizing the oxidation of chloroauric acid and the reducibility of several reducing agents [1].

In terms of principle and development process, the preparations of silver nanoparticles can be divided into direct preparation methods and indirect preparation methods. Directly, there are vacuum gas condensation methods, sputtering methods, laser high-temperature combustion methods, mechanical grinding methods, etc. However, what is above was invented long ago. There are several novel or improved methods nowadays. For instance, the anode arc discharge plasma method is an optimized version of the condensation method. The diffusion process is accompanied by the collision and coulomb collision between charged particles and neutral particles in the ground and excited states, and the particles are continuously ionized and recombined to obtain sufficient energy and charge exchange.

Due to the convection of the inert gas, the metal vapor rapidly loses energy and cools as it approaches the cooling collector, resulting in a locally high degree of supersaturation, resulting in a homogeneous nucleation process. In the formation process of metal particles, atomic clusters first appear, followed by the precipitation of monodisperse crystal nuclei, and finally the growth and condensation of crystals. After quenching by the quenching device, energy is rapidly lost, forming nanoparticles deposited in the cooling collection cylinder [2]. There are several aspects of medical implants, including dental implants, orthopedic implants, soft tissue implants, detection implants, etc. Sometimes, implants are classified by the material, like metal-based or organic material-based. The development of medical implants recently is remarkable. For instance, functional graded materials show their novel value in bio-medical implant, and the effectiveness of them are clarified. In terms of the structure, for example, the porous medical implant scaffolds is are tested to be feasible in additional manufacturing for medical implants. Although medical implants contain numerous aspects, nanoparticles, as basic materials, can demonstrate their uses in three aspects of implants which focus more on materials, which are dentistry, orthopedics and soft tissue [3,4].

2. Properties of two kinds of nanoparticles

2.1. Physical properties of gold nanoparticles

The properties of GNPs have been adequately revealed by numerous researches. As far as physical properties are concerned, the following are probably the most typical characteristics. The first is the optical effect, where certain wavelengths of light can be selectively absorbed or scattered depending on the grain diameter [5]. However, the vast majority of the lights would be absorbed rather than scattered. Since most of the absorbed light has a wavelength of around 520 nm, solutions of GNPs are typically red, as defined by the colorless principle. Second The second is plasmon resonance, GNPs shows surface plasmon resonance, which means that the surface of GNPs would experience electron cloud resonance because of the electromagnetic wave of the Incident lights. The third is the surface effect, since GNPs are very small in size, the surface of a grain occupies dramatically more than others. The ratio of the number of atoms on the surface to the total number of atoms in the gold nanoparticles changes, i.e., the change in particle size, especially the change of decreasing and then suddenly increasing, will have an effect on the surface area of the particles, the surface energy, and the overall surface, and a significant change in the surface binding energy can be observed.

2.2. The chemical characteristics of GNPs

The following chemical characteristics of GNPs may be utilized in medical implants. The first is the fluorescence property, which becomes apparent when GNPs are modified and encapsulated with different detection groups [5]. The appearance of fluorescence is a result of resonance energy transfer. The second is supramolecular and molecular recognition, the supramolecular and molecular recognition properties of GNPs refer to the use of chemical methods to control the assembly behaviour of these nanoparticles. Through the selective attachment of hydrogen bonding, van der Waals forces and chemical covalent bonding, GNPs can form supramolecular structures with specific molecular recognition motifs, and other nanoparticles, or assembled onto specific substrates. The third is the adsorption property, where GNPs consisting of a limited number of gold atoms have distinct surface features compared to their internal atoms due to the crystal field environment and binding energy. This

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results in the presence of vacancies on the surface, making it unsaturated and highly reactive towards other atoms.

2.3. Characterization of silver nanoparticles (SNPs)

Since both GNPs and SNPs are nanoparticles, they share many common properties. The following are the properties of SNPs that differ from GNPs. First of all antibacterial properties, silver ions have strong antibacterial properties and have the second second-highest bactericidal activity of all metals. Studies have shown that silver ions can disrupt the respiratory function of bacteria and viruses, interfere with cell membrane function, and bind to bacterial cell DNA to inhibit cell division. In addition, the antimicrobial effect of SNP is significantly higher than that of conventional silver ion disinfectants [6]. Secondly, catalytic effect, a large number of studies have shown that SNPs have obvious catalytic effects. For example, Han Minghan et al. prepared nanoscale silver-deposited TiO materials for photocatalytic reduction of ions using vacuum deposition. It was shown that both titanium- and silver-based photocatalysts exhibited effective catalytic activity in the reduction of Se (VI) in the presence of formic acid [7].

3. The applications of GNPs and SNPs in dental implant and their differences

Generally, there are two approaches to applying nanoparticles to dental implants. One is an exterior method, as a film or coating, while the other is an interior method, as a co-structure with the material of implanted teeth, like a ceramic teeth structure with GNPs which can increase the wear resistance of porcelain tooth structure [8]. However, because of certain characteristics of nanoparticles, it they seem more common in the exterior one when researchers are applying them. As a result, attention is paid more on to the exterior application of these two nanoparticles in dental implants in the following review.

3.1. GNPs film improves the strength of implanted teeth

According to the research about optimizing Ti-ceramic combination by GNPs Film Deposition Technology conducted by Li et al., they utilized the Ionic Self-assembled Multilayers, namely ISAM, to construct a GNPs layer between Titanium and ceramic. To be specific, the electrostatic force between two solutions of two different electrical properties, negative and positive, makes the solutions on two sides of a pure Ti test piece get attached to it. GNPs are in a polyanion solution while PAH (Poly Allylamine Hydrochloride) is in a polycationic solution. After repeated assembly of two-side solutions and air drying, there will be GNPs left on one side of the test piece. Subsequently, porcelain sintering is done between Ti and ceramic. According to the conclusions coming from (1) three-point bending test and fracture mode observation, (2) combined interface observation and (3) FE-SEM, stereomicroscope and EMP observation, it is clear that the GNPs film between Titanium and ceramic can enhance the combination strength, with stability and biocompatibility [9].

3.2. SNPs coating improving improving mold resistance of implanted teeth

Liu et al. studied the application of SNPs coating in dental implants and showed that GNPs have the advantages of high safety, good heat resistance, wide antibacterial range and long-term sterilization. In addition, the nanomaterial itself has the characteristics of quantum effect, small size effect and large specific surface area, which makes the surface of the implant containing the nano silver coating have excellent antibacterial ability and durability. At the same time, surface silver nanoparticles had no effect on the growth and development of gingival fibroblasts. Therefore, Gnps Gnps-coated implant abutments have an antibacterial effect and good biocompatibility, which is an ideal choice [10]. Liu et al. have also discovered nano-zirconium phosphate silver silver-bearing antibacterial powder by liquid phase coprecipitation method, whose rate of antibiosis can even reach the peak of 99.9% when the powder accounts for 2.0%, indicating that there is a promising future for this application in dental implant [11].

4. The applications of GNPs and SNPs in orthopedic implant and their differences

4.1. GNPs possible application in orthopedic implant

There have been some researches regarding the application of GNPs in orthopedics like polydopamine-coated graphene oxide composites supported by gold nanoparticles repairing defective bones as a holder. The bioactivity of PLGA scaffolds was improved by blending Lys-g-GO nanoparticles with Au NTP-PDA surface functional coating. These two methods complement each other to a certain extent and synergistically enhance the bone repair ability of scaffold materials. GNPs-PDA@PLGA/Lys-g-GO composite porous scaffold has good hydrophilicity, mechanical strength and antibacterial properties. In vitro experiments showed that the composite scaffold could significantly enhance the adhesion, proliferation, osteogenetic differentiation and calcium deposition of osteoblasts. In vivo experiments have shown that it promotes the production of new bone and collagen matrix. Therefore, this functional scaffold material has a broad application prospect in the repair of bone defects [12]. However, those about prosthesis implants are rare. Most of the research concerning ‘GNPs’ and orthopedics, simultaneously points to their capability in bone regeneration and recovery in certain ways. it is proved that GNPs can affect the proliferation, differentiation and mineralization of bone cells MC3T3-E1, resulting in promoting osteogenic differentiation and mineralization of MC3T3-E1 cells [13]. In addition, the effect varies according to the grain diameter of GNPs. It turns out that Runx2, BMP-2, ALP and OCN4 genes interact with each other to stimulate the osteogenic differentiation of MC3T3-E1 cells. Accordingly, GNPs may function in holder implants and coating rather than in prosthesis implants.

4.2. SNPs application in Orthopaedic implant

Guan Jie et al. study the cytotoxicity, antibacterial activity and osteogenic activity of β-TCP-Ag composite scaffold containing 5% (mass fraction) silver nanoparticles on rabbits, providing a new idea for the clinical treatment of osteomyelitis complicated with large area bone defect [14]. The tricalcium phosphate composite scaffold containing 5% nano silver has good biocompatibility and antibacterial ability, which is conducive to the healing of bone defects after killing bacteria in the body, and is a good antibacterial and bone defect implant material. In another research, attention was paid to silver-carrying antibacterial nano-composite bone filler [15]. "Atmospheric pressure co-solution method" was used to prepare TiO2-Ag-nHA/PA66 nano-antibacterial composite bone filling materials, and to study the antibacterial effect of silver-loaded nano-antibacterial composite bone filling materials in vitro. It turns out that this material is able to be applied to fill bone defects after chronic osteomyelitis, with an outstanding quality antibacterial properties.

5. The applications of GNPs and SNPs in Soft tissue repair implant and their differences

5.1. GNPs application in soft tissue repair implant

There have been some researches regarding the application of GNPs in orthopedics like polydopamine-coated graphene oxide composites supported by gold nanoparticles repairing defective bones as a holder. The bioactivity of PLGA scaffolds was improved by blending Lys-g-GO nanoparticles with Au NTP-PDA surface functional coating. These two methods complement each other to a certain extent and synergistically enhance the bone repair ability of scaffold materials. GNPs-PDA@PLGA/Lys-g-GO composite porous scaffold has good hydrophilicity, mechanical strength and antibacterial properties. In vitro experiments showed that the composite scaffold could significantly enhance the adhesion, proliferation, osteogenetic differentiation and calcium deposition of osteoblasts. In vivo experiments have shown that it promotes the production of new bone and collagen matrix. Therefore, this functional scaffold material has a broad application prospect in the repair of bone defects [16]. However, those about prosthesis implants are rare. Most of the research concerning ‘GNPs’ and orthopedics, simultaneously points to their capability in bone regeneration and recovery in certain ways. it is proved that GNPs can affect the proliferation, differentiation and mineralization of bone cells MC3T3-E1, resulting in promoting osteogenic differentiation and mineralization of MC3T3-E1 cells [17]. In addition,

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5.2. SNPs application in soft tissue Repair implant

Xia et al. have researched SNPs' possible application in engineering tissue, and skin. SNPs bionic dressing is sterile, pyrogen-free and non-irritating [18]. It is non-toxic and has the function of promoting wound healing, shortening the wound healing cycle and anti-infection, while reducing the possibility of argyria and improving nano-Biosafety biosafety of materials; SNPs or carboxymethyl chitosan biological dressing not only has strong broad-spectrum antibacterial properties but also does not produce drug resistance. It can also promote the growth of epithelial cells, fibroblasts and vascular endothelial cells, significantly promote wound repair, and can significantly promote ulcers. Selective wound growth and healing, shorten skin healing time, and achieve physiologic repair. Plastid cells proliferate rapidly and maintain their biological activity.

6. Suggestions

To sum up, generally, GNPs are more utilized according to their stability, biocompatibility, coordination functions and promotion mechanism in the human body, while SNPs are more used according to, most significantly antibacterial properties, biocompatibility and coordination functions. To put them in comparison, their application is sometimes similar. For instance, when it comes to the exterior layer of implanted teeth, both of them show irreplaceable values: antibacterial property and combination enhancement. However, there are certain situations that these two can't be easily positioned together. In several researches, it is pointed out that SNPs show a possibility of toxicity which deserves attention, while GNPs' toxicity has been widely recognized as unharmful. In addition, when comparing the antibacterial property, it is worth considering whether GNPs shows equivalent value in certain fields. In terms of structural functions, such as GNP film improving Titanium-ceramic bonding, if it is possible that SNPs film can demonstrate the same functions, the antibacterial property of SNPs may bring more considerable benefits than GNPs. Furthermore, there rarely are is research studying the cooperation between GNPs and SNPs. If there is a chance that the antibacterial property and supramolecular and molecular recognition can be coordinated with each other, delivery of medical drugs into specific areas of the body would be promising. In orthopedic implants, it is rarely studied that GNPs and SNPs are utilized in prosthesis implantation. Instead, on a regular basis, they serve as holders, support, film and coating. If certain structures that take advantage of the prospective characteristics of GNPs and SNPs can be designed, lighter, safer and firmer prosthesis implants may be invented.

7. Conclusion

All the above reviews the applications of gold nanoparticles and silver nanoparticles in the main aspects of medical implants, including dental, orthopedic and soft-tissue implants. Then, the similarities and differences in the application of the two nanoparticles, as well as the advantages and limitations of each. This review shows some remarkable values in comparing the distinct characteristics and applications of gold nanoparticles and silver nanoparticles by their separate features in dental implants, orthopedic implants and soft tissue implants. And this may path pave the way for those who need to decide which nanoparticle is more suitable when it comes to a certain field of medical implant. But there are some limits in this review. Some applications are assumed to be feasible but not proved proven yet, which require further researches to explore or clarify. In addition, the applications of nanoparticles in other implant fields can hardly be searched. This may be due to the complex molecule's reactions concerning the nanoparticles, especially gold nanoparticles, which have been proved proven to be able to adjust some in-vivo regulatory mechanisms. Not only does biocompatibility matter, but whether hormones or chemical reactions in the body would be affected by nanoparticles, which are distinctively small for human cells, deserves more researches. In terms of the nerve repair implants, it is true that nanoparticles show their distinctive biocompatibility, but whether gathering the metal elements in a fragile nerve system would cause irreversible problems requires detailed researches before practical applications.

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