Application of Different Nanomaterials in Biomedical Field

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Abstract. Nanomaterials is the most promising materials in biomedicine because many of its features can be used to go deep into places which cannot be touched by traditional treatment methods. As a result, a diverse of different nanomaterials are quickly growing to be one of the most important materials in biomedical fields. In many cases, nanomaterials show great promise in further improving the efficiency of medical treatment, where they are very beneficial for drug delivery. This research will analyze the application principles of nanomaterials and explain why and where to use nanomaterials in medicine and treatments. More specifically, this research will introduce some application status of nanomaterials in the field of biomedicine, including cancer treatment, the treatment of coronary artery disease, biomarkers detection and Nano antibacterial agents.

Keywords: Nanomaterials, Application, Biomedicine.

1. Introduction

Biomedicine is receiving increasing attention. Whether biologists or chemists, are working on research methods for various diseases treatments. There are many branches of biomedicine, including biochemistry, biological engineering, embryology and cell imaging. Nowadays, biomedicine is in a stage of vigorous development, and some research projects based on this, such as the Human Genome Project, also affect the future of human beings. Through the development of biomedicine, many intractable diseases have finally been cured, and diseases considered as terminal diseases have also become curable. Even in cancer, biomedical scientists are actively looking for a cure, and cancer vaccines are one of the great achievements of modern biomedicine.

However, there are still many side effects in the existing medical technology, such as the damage caused by chemotherapy to the human body. There are also cases where particles are needed to deliver drugs, often because the molecules are not small enough and the dose needs to be increased. Under this circumstance, nanomedicine came into being. Comparing to traditional materials, nanomaterials have many advantages in many different areas. The small size of nanomaterials offers the possibilities of manipulation easier, and multiple functions can be accommodated. In industries, the high porosity of nanomaterials increases its demands. For example, in energy sector, the usage of these nanomaterials makes the existing methods of energy generation cost-effective and efficient [1]. Nanomaterials also have advantages in industry of electronics. The involvement of nanomaterial increases accuracy while constructing the circuits on atomic levels. Compared to the coarsely grained ceramics, ceramics made of nanophase is more ductile during elevated temperatures. There are still many problems in today's medical area which is hard to solve by the traditional technology. However, the introduction of a diverse of different nanomaterials with excellent chemical properties may offer an unprecedented scheme to solve such problems.

Nanomaterials enable precise control of individual atoms and molecules within the material and have critical applications in the biomedical field. The prepared nanoparticles can be characterized by small grain size, fewer atoms inside the grain than on the crystal surface, surface effect with high

concentration of grain boundaries, small size effect, and quantum tunneling effect. Nanomaterials exhibit excellent optical, electrical, and magnetic properties compared with conventional macroscopic materials, such as carbon nanomaterials, rare earth nanomaterials, composite nanomaterials, semiconductor nanomaterials and precious metal nanomaterials [2].

People are healthier in order to live, so people pay more attention on health problems. Application of nanomaterials in the field of biomedicine has a wide development. Now people are researching the use of nanotechnology to treat their own physical diseases, who want to live longer. At present, the three methods of cancer treatment in hospitals are surgery, radiotherapy and chemotherapy. However, all three methods carry the risk of damaging normal tissue or not completely eradicating the cancer. Nowadays globally, researchers are studying controlled drug release targeting cancer cells as an alternative to chemotherapy. The main purpose is to reduce the risk of cancer patients and improve the patient's chance of survival, while also reducing the suffering of patients during the treatment process. The main treatment method of this prescription is to use target cells to actively carry out targeted treatment of cancer cells, thereby improving the efficiency of treatment. It is precisely because of the wide application of nanomaterials in the field of biomedicine, this research will introduce some application status of nanomaterials in the field of biomedicine, including for the treatment of cancer, for the treatment of coronary artery disease, for the detection of biomarkers and Nano antibacterial agent.

2. Application of nanotechnology in the treatment of cancer

Nanomaterials also play a key role in cancer treatment [1], as shown in Figure 1. Using the special properties of nanomaterials, scientists have made remarkable progress in cancer treatment. Through case studies, organic and inorganic nanomaterials with different sizes below hundreds of nanometers are becoming a promising tool for the treatment and diagnosis of cancer due to their unique passive tumor orientation. The wide application of platforms such as polymer colloids, liposomes, dendritic macromolecules, and polymer nanoparticles has been widely studied for the targeted delivery of anticancer drugs, which allows drugs to selectively transfer payloads to the required tumor tissues because they can accumulate in tumor tissues through the leaky vascular structure. In other words, nanomaterials can be used as drug carriers to penetrate places that cannot be covered by traditional medicine, such as the interior of cells. These nanomaterials can also be used to form cancer. In addition, the optical imaging method is introduced into the nanomaterial delivery system in particular, quantum dots are widely used in nanoparticle release systems to study their migration in vitro because of their high fluorescence and high light resistance. This allows doctors to know where particles move and the resistance they experience. Therefore, they can better plan to treat patients. The drugs contained in nanomaterials usually stay in the blood for a long time, increasing the spread of tumors and reducing toxicity, to obtain a higher dose. This allows drugs containing nanomaterials to obtain vital organs without any surgery. In addition, due to the specific physical and chemical properties, some nanomaterials themselves can regulate the immune response.

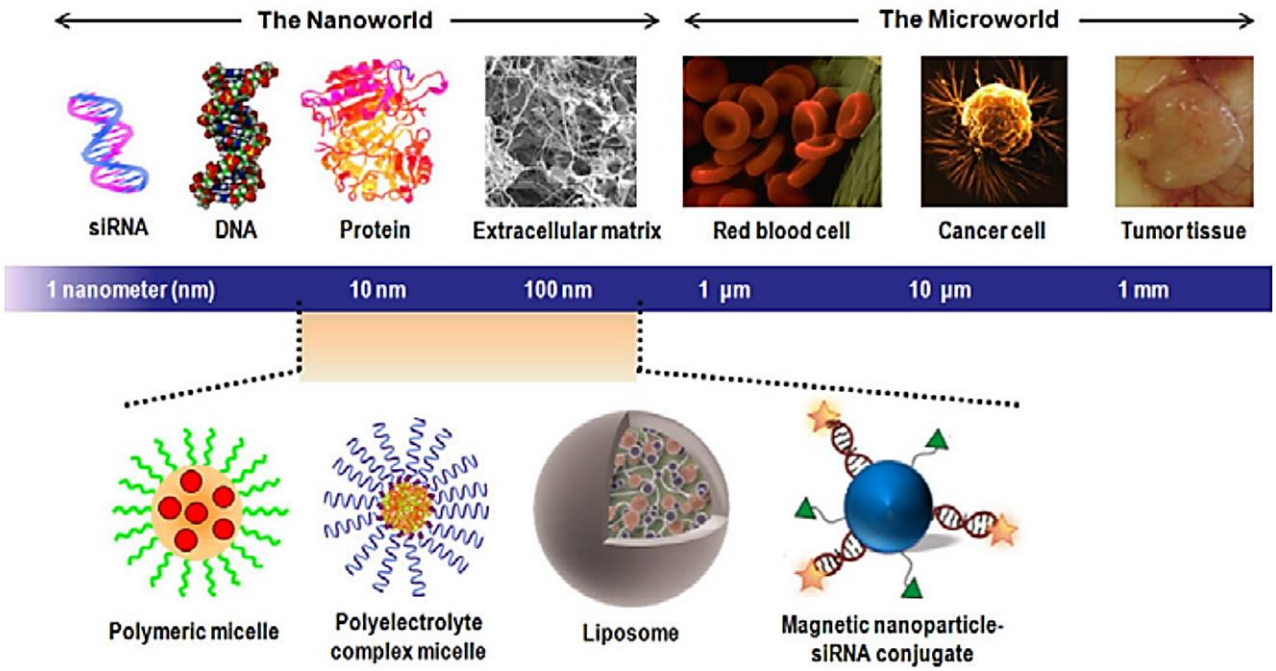


Figure 1. Some important biological systems and nanomaterials with different sizes [1].

Another part of the study shows the application of nanomaterials in the development of cancer vaccines [2]. In the process of research, some nanomaterials may be inherent characteristics of cellular and humoral immune response, because they can promote the development of antigen or stimulate immune response without adding specific additives. This has promoted the production of vaccines and provided a simple and powerful strategy for expanding antitumor immunotherapy. However, according to this study, the therapeutic effect of cancer vaccine is still not ideal. One of the important reasons is that due to the application of traditional vaccination methods, antigens (especially subunits) are rapidly destroyed and degraded, and the use efficiency of DC and antigen is low. In addition, the clinical independence of antigens and additives as a free and independent form may lead to immune tolerance, because DC has no “danger signal” when encountering antigens.

3. Application of nanomaterials for coronary artery disease treatment

Nanotechnology can provide a new idea and therapeutic approach for coronary artery disease (CAD) treatment, which is a serious disease. And the breakthrough points in using nanotechnology to treat this disease is the treatment of atherosclerosis and CAD. Among these things, because many biological factors and cellular disease processes are involved, these processes can be alleviated with treatments enhanced by nanotechnology. This because the small size of nanomaterials can be used to transport substances such as drugs and genes through the use of nanoparticles, as shown in Figure 2. At the same time, nanotechnology can also be applied to the aspect of cardiac stents [3].

The CAD is caused by the accumulation of atherosclerotic plaque in the lining of the coronary arteries, which can cause serious harm to the human body. Because it is part of the heart muscle, when the blood supply to the heart muscle is severely restricted, there is an angina or chest pain. And in severe cases, shock and death can occur. Coronary blood clots can block the blood supply to the heart, causing heart disease. This phenomenon can lead to the rupture of atherosclerotic plaque in the CAD, making heart disease worse.

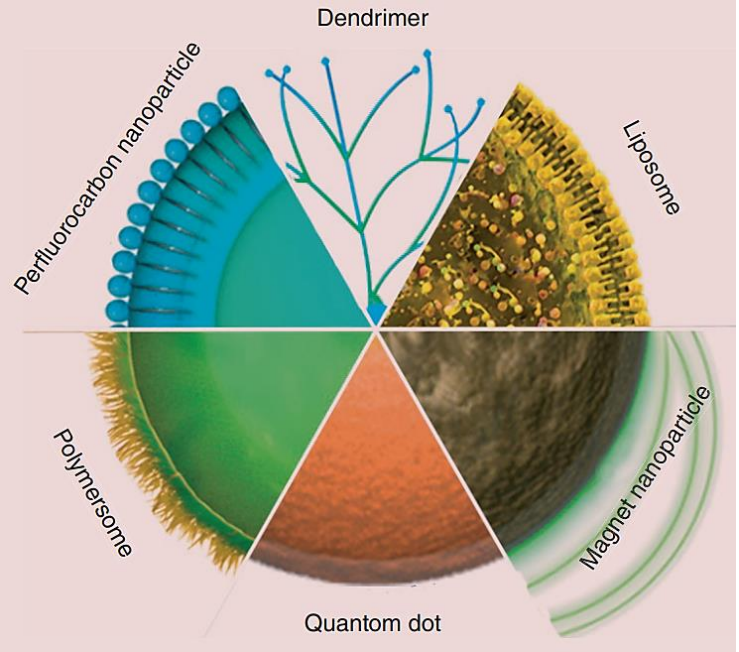


Figure 2. Schematic diagram of the structure of different nanomaterials [3].

Atherosclerosis is the thickening of the walls of arteries because of the formation of atherosclerotic plaques and the spread of atherosclerotic lesions. In this condition, there are proliferating cells and more nutrients and oxygen are required. In order to meet the nutritional needs, endothelial cells proliferate to form immature and atypical new blood vessels. This situation prevents the transport of macromolecules, so that nanomaterial transport must be used to target the inflamed area [4]. There has been a huge breakthrough in the application of nanotechnology in heart surgery. For example, a net-shaped polyester sheath is wrapped around the heart to help it contract and prevent it from expanding, effectively restoring its normal function. The new technique has been successful in animal experiments and will soon be used in patients undergoing clinical surgery.

4. Application of nanomaterials for biomarker detection

Nanomaterials are at least one-dimension (1-D) in the nanoscale (that is, from 1 nm to 100 nm) in the three-dimensional (3-D) spatial scale. And there are many ways to classify nanomaterials, such as by the number of dimensions of nanomaterials can be divided into spatial 3-D homogeneous. Their particular structure makes nanomaterials exhibit many unique properties different from microscopic particles and macroscopic substances, such as optical properties, catalytic properties and adsorption properties. These properties allow nanomaterials to exhibit many excellent properties in optics, electricity, magnetism, and thermodynamics, thus leading to a wide application in biomedicine, food analysis and environmental monitoring [5]. For example, in the field of electrochemical analysis, a diverse of different nanomaterials be able to modify the electrode to improve the effect of electroanalysis [6]. As a result, it can provide a good microscopic environment for biomolecules, by facilitating electron transfer, using as signal molecule carriers or signal markers. Electrochemical analysis built with nanomaterials can have some advantages, such as good selectivity, ultra-high sensitivity, stability and faster response rate. Therefore, different nanomaterials have been synthesized by using various synthetic methods, like metal nanomaterials, polymeric nanomaterials and composite nanomaterials.

Metal nanomaterials such as gold nanomaterials, silver nanomaterials, and platinum nanomaterials are widely used in virous biosensors for the detection of biomarkers in biomedicine because of their excellent physical and chemical properties. Among them, gold nanomaterials are the most commonly used for the biomarker's detection. It is generally dispersed in an aqueous solution, so people also call it colloidal gold or colloidal gold. Facile preparation of gold nanoparticles generally uses the

reduction of the chloroauric acid method, common ascorbic acid reduction method, sodium boron oxide reduction method, and trisodium citrate reduction method. These gold nanoparticles usually show high stability and good biocompatibility so that the use of their solid loading and labeling of proteins will not destroy their biological activity. In addition, gold nanoparticles can covalently bind to flow groups to form strong Au-S bonds, which allows gold nanoparticles to bind to sulfhydryl-modified bioactive molecules to form biomolecular probes [7]. Biological protein molecules can also be bound to the surface of gold nanoparticles with electrostatic and hydrophobic interactions, where the formed complexes can maintain the biological activity of the protein for a long time.

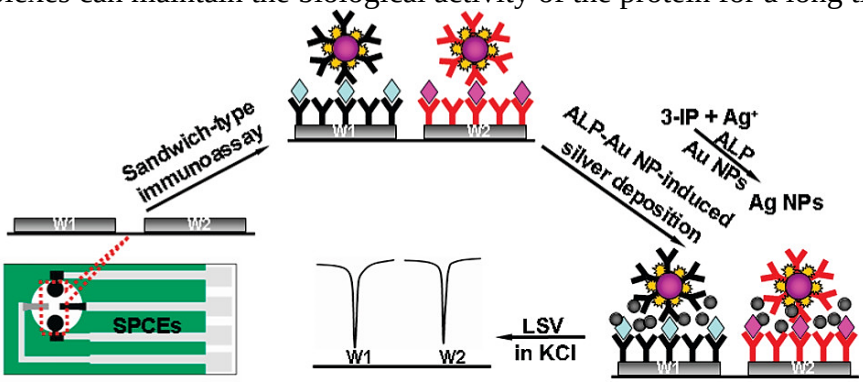


Figure 3. Schematic diagram of the developed electrochemical biosensor [8].

Ju et al. developed a novel ultra-sensitive immunosensor assay by using gold nanoparticles loaded with alkaline phosphatase (ALP) labeled antibody molecules and enzymatic gold nanoparticles catalyzing silver deposition [8], as shown in Figure 3. The obtained response signal was greatly amplified by the co-catalysis of the ALP and gold nanoparticles. Using this developed biosensing method, the limit of detection for human and mouse IgG was as low as 4.8 pg/mL and 6.1 pg/mL, respectively. Carbon-based nanomaterials have excellent electron transfer capabilities and good biocompatibility, which is similar to metal nanomaterials and show compatibility, high biomolecular loading capacity and many other properties. In-depth studies on carbon-based nanomaterials' physicochemical properties and functions have made them an active class of materials in the development of different biosensors in biomedical field. As a result, a diverse of virous carbon-based nanomaterials have been widely used: carbon nanospheres, carbon nanotubes, graphene and carbon nanofibres. The following is an introduction to carbon nanotubes and graphene.

Carbon nanotubes is gradually growing one of the most studied nanomaterials since they were first reported in 1991, which mainly include single-walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT) based on the number of layers in their walls. As 1-D nanomaterials, carbon nanotubes have a series of unique properties, such as large surface area, good mechanical strength, good thermal stability and excellent heat transfer and electrical conductivity. In addition, the sp2 hybridization of the carbon atoms in the sidewalls forms a highly hydrophobic and highly exotic structure, which can be non-covalently bonded to electron-containing substances via π-π interactions. When these types of nanomaterials are acidified, a large number of oxygen-containing functional groups can be added to carbon nanotubes, thus allowing for more effective covalent modifications [9], as shown in Figure 4. According to the above principles, carbon nanomaterials can be used for the detection of biomarkers in two main ways: (1) using their good conductive and catalytic properties as electrode modification materials that can accelerate the speed of electron transfer, (2) using the large surface area as carriers to increase the loading of biomolecules to amplify the signal.

As the world's thinnest 2-D material, graphene is one of the new carbon materials with a unique structure and good properties [10]. It shows enormous specific surface area, high electron conduction capacity, superb mechanical strength, good processability and low cost. The good electrical conductivity and macroscopic tunneling effect of graphene make it an effective electronic mediator between the electrode and the immobilized enzyme. This is not only enabling direct electron transfer

from the enzyme active center, offering the possibility of detecting glucose and other substances, but also increasing the response current, reducing the analysis time and improving the sensitivity of the developed biosensors [10]. In addition, graphene's good biocompatibility allows it to be used for the immobilization of biological protein molecules. Therefore, in recent years, it has become popular to study the application of graphene in different kinds of biosensors [11].

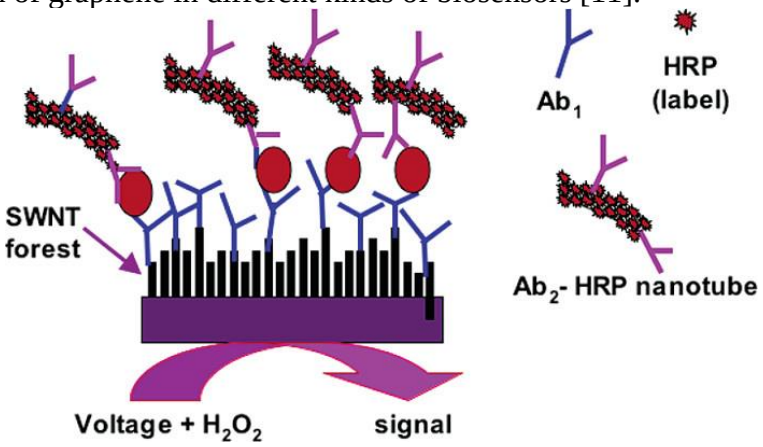


Figure 4. Schematic diagram of electrochemical bioosensor based on SWNT [9].

Li et al. constructed a bi-amplified electrochemiluminescent sandwich immunosensor by using a chitosan-dispersed graphene-modified electrode as a biosensing platform for immobilizing antibodies, combined with gold nanorods-loaded glucose oxidase and secondary antibodies [12]. In this sandwich structure, functionalized graphene can facilitate the transfer of electrons on the surface of electrode. At the same time, its large specific surface area is utilized to load more trapped antibodies (Ab1), and gold nanorods are used not only as a carrier for secondary antibodies (Ab2) but also to catalyze the luminol reaction. The designed biosensor exhibits high sensitivity and strong specificity for the detection of PSA, where its detectability is also as low as eight pg/mL.

5. Nano antibacterial agent

Dental health is one of the important issues that people have to deal with. In addition to tooth decay, gingivitis, gum recession and other conditions, implants and coatings used for treatment can also cause some adverse reactions. For dental implants, preventing the entry of oral microorganisms is essential. In these cases, scientists conducted a series of experiments aimed at extending the antibacterial properties of the dental coating and the promoting effect of the coating on osteoblasts. Nano-sized particles (that is, nanomaterials) increase surface area, reduce shear forces, and increased bacterial and osteoblast adhesion [13].

For specific titanium-based nanocoatings, metal ions such as silver nanoparticles produced by laser ablation will electrostatically adhere to the bacterial cell wall and cytoplasmic membrane, causing damage to the bacterial DNA and protein structure, thereby inhibiting bacterial growth [14]. The low doses of Ag incorporated in dental implants not only can enhance antibacterial ability of the implant but also keeps surface's biocompatibility. Zn can be used in the modification of implants because it not only has antibacterial but also osteogenic. For example, Zn was incorporated into TiO_2 to coat titanium implants by plasma electrolytic oxidation, and bactericidal and growth effects were observed [15]. Substrates coated with ZnO nanoparticles significantly reduce bacterial proliferation. Compared with the first two, copper oxide is more economical, has higher chemical stability and is easy to combine with polymers. Scientists coated titanium implants with CuO nanoparticles and calculated the diffusivity of antibacterial drugs [16]. The measured results showed that the titanium implants coated with CuO nanoparticles had high antibacterial activity against test organisms. Study results suggest Cu ions can help control local infection around implants, and TiO_2 coating doped with micro-arc oxidation of Cu exhibits excellent antibacterial activity [17]. Also, CuO nanoparticles limit bacterial growth by passing through the nanopores present in most bacterial cell membranes. For

zirconium and zirconia, their biocompatibility, corrosion resistance and excellent mechanical properties make them good dental implants. The bioactivity of the implants can be enhanced due to the nanometer roughness of the nanotubes and nanopores made of ZrO_2 [18], as shown in Figure 5. Although these metal ions are all cytotoxic under specific conditions, the adhesion and proliferation of osteoblast as well as endothelial cells *in vitro* can still be enhanced.

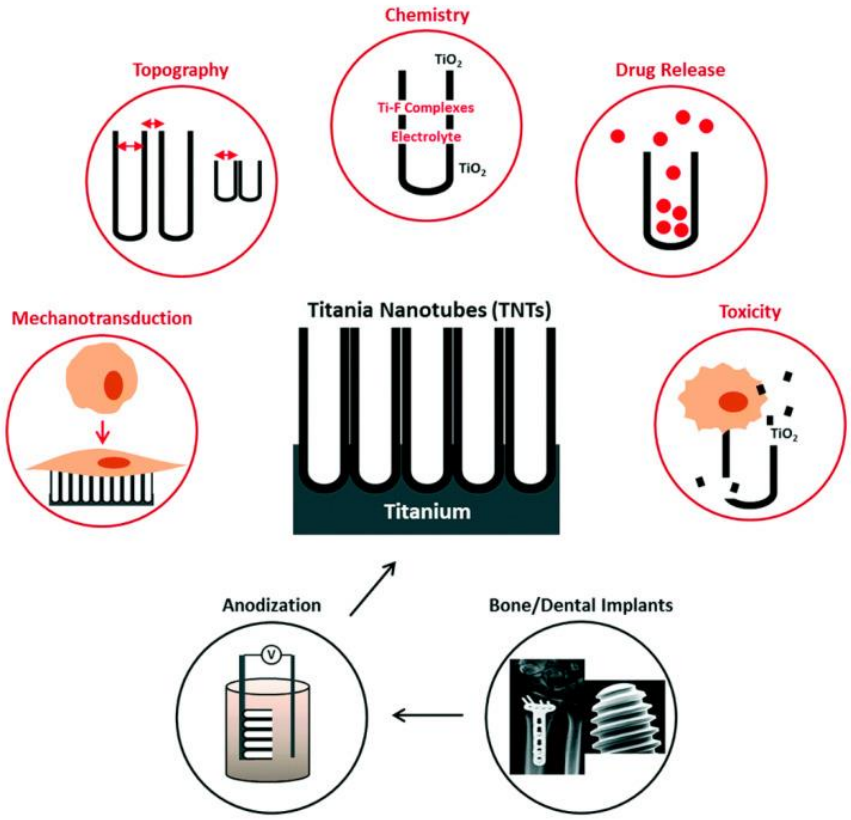


Figure 5. Bioactivity enhancement and topical therapy based on titanium dioxide nanotubes [18].

Biopolymers are also a good choice for nanomaterials, because of the antibacterial and non-toxic properties of chitosan [19]. It can destroy negatively charged bacterial cells to achieve bactericidal effect. When chitosan was incorporated into the implant surface in the form of nanoparticles, it exhibited high loading rate and sustained drug release capability. In addition, adding calcium derivatives to the nanocoating can cooperate with its antibacterial effect to reduce tooth erosion. Nano antibacterial agent implants have made outstanding clinical contributions. Compared with traditional methods, nanomaterials have higher bacteriostatic rate and improved osteogenesis ability. By comparing the properties of metal ions and biopolymers, modern medicine can choose the appropriate treatment with relative ease. It also lays the foundation for implant research outside of stomatology. In general, nanoimplants hold great promise, not only in dentistry, but in the whole bioscience.

6. Conclusion

Nowadays, nanomaterials are significantly more advantageous than traditional materials in many ways. Based on the excellent chemical, optical, magnetic, and electrical properties of nanomaterials, the introduction of a diverse of different functionalized nanomaterials for the development of various medical technologies has gained widespread interest. This research is carried out in this context, and the main work consists of the following parts. First, nanomaterials can play an essential role in cancer therapy by acting as carriers of drugs. Second, nanomaterials can be used for transport and cardiac stents to help treat coronary artery disease. Third, nanomaterials show wide applications in

biomarkers detection. Fourth, two types of nanomaterials, metal ions and biopolymers, are useful for improving the rate of bacterial inhibition.

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