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Application of Nanomaterials for Surface Modification of Dental Implants

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Abstract: Dental implants are a very important branch in implant medicine, in which the loss of teeth can cause a lot of inconvenience and affect the function of the alveolar bone at the same time, making the basic oral metabolism of the patient disturbed and affecting the quality of life. The placement of implants has become one of the effective methods of restoring missing teeth. However, there are some problems within the implant dentistry community, mainly manifested by the occurrence of inflammation after dental implants, making it difficult to guarantee the most important success rate. Given the previous medical approach, the success rate of dental implant placement can be ensured and improved by the development of relevant biocompatible materials through the surface treatment of implants. The challenges faced now are mainly cytotoxicity and biocompatibility. After consideration, it was found that the use of nanomaterials can be a good solution to the problems faced by dental implants, and their excellent physical properties and sterilization can guarantee the success of implants. Therefore, this paper provides an overview and outlook on the selection of dental implant materials, surface treatment, and especially the application of nanoparticles in surface treatment, showing good prospects for the application of nanomaterials within the field of dental implants.

1. Introduction

Dental implants are now a more common way to replace the natural or missing teeth of the repair patient and also provide a complete restorative option for missing teeth[1][2] . With the continuous development and refinement of implant medicine technology, it is visible and perceived that dental implants are becoming more and more perfect in terms of material, which shows better implant and healing results. The stability and long-term clinical success of dental implants depend on the osseointegration[3][4], i.e., they depend exclusively on the implant material properties, which makes the optimization and selection of implant materials particularly crucial [5]. Nanotechnology is one of the important technologies that are currently receiving much attention within the industry in many disciplines, and the main value of nanotechnology is the use of nanoscale particles with a diameter of 1-100 nm, which become nanoparticles, for relevant experimental studies[6].

Within the academic scope explored in this paper, nanotechnology is mainly used in the dental field to apply implantable nanotechnology for disease prevention purposes [7][8][9].

Metallic and organic nanomolecules have been used in some dental applications due to their broad-spectrum bactericidal ability [10]. However, there are still many difficulties to be solved in the use of nanotechnology within dentistry. Such as cytotoxicity, oral infection and gingival resorption [11]. An important factor in implant medicine that determines long-term clinical success is the properties of the implant surface [12].

Later with the work done by Branemark in 1960, the concept of osseointegration was introduced as a key factor for the long-term success of dental implants [13]. In the osseointegration process, hydrophilicity and surface roughness have a great influence on the process of osseointegration [14]. From the history of dental implant development, since 1970, the surface of dental implants has undergone further refinement in clinical applications, from pure titanium (cp-Ti) machined surfaces to further refinement to microstructures, with the emergence of nanostructure modification, chemical modification, nanostructure modification, wettability control, and many other developments and applications for implant surface modification[15][16][17].

Nanoparticles have more advantages than the usual surface modification techniques for dental implants: better biocompatibility, larger surface area and stronger mechanical properties. The application of nanotechnology in dental implants is still in the developmental stage, but there are already research results and examples of their use [18]. Nanometallics such as zirconium, zinc, titanium and silver are available in sizes ranging from 1 to 10 nm. According to existing research findings, nanometals have been shown to have stronger antimicrobial properties compared to large particle dental implant surface modification molecules [19][20].

At the end of the last century, nano-methods for surface modification of dental implants were investigated and surface modification was first introduced in implant medicine for screw-shaped implants in bone to achieve better implant results through chemical modification and surface modification and other surface topology changes. The most important surface modification methods used are sandblasting and anodizing of the implant surface, which are widely used in clinical practices[21].

Initially, the effectiveness of nanoremodeling was questionable considering the size of the bone abrasives and bone, since complete bone growth does not occur in spaces smaller than 100 mm. However, according to relevant studies, the surface nano-modification component affects protein adsorption, bone-implant interactions and osteoblast behavior. Surface modification for dental implants is a physically or chemically modified modification method that targets the bone - implant interface where it occurs. This paper provides a brief description of the application of nanotechnology to dental implants and briefly discusses surface modification methods for dental implants that can be implemented to improve the hard tissue response at the bone-implant interface for better implant and healing results.

In order to promote osseointegration, the development and exploration of implant medicine has led to the proposal of surface modification methods such as the type and modification of the implant surface, the normal occurrence of osseointegration being the basic prerequisite for a successful implant [22]. The nano-surface treatment of dental implants was analyzed and discussed, and the material selection, nano-particle characteristics, surface modification methods, and nano-coating types were discussed and investigated, proving that nano-particles have good performance and development prospects in the modification of dental implant surface treatment, followed by a discussion on the application of nanotechnology in implant medicine in the third part, specifically on copper, silver, and several other types of nanoparticles. In the third part, we discuss the application of nanotechnology in implant medicine, and specifically analyze the impact of the antimicrobial effect of several nanoparticles, such as copper and silver; finally, we conclude that nanotechnology has great potential for application, and its excellent mechanical properties, high surface-to-volume ratio, and ability to prevent crack propagation are of great interest. The multiple forms of nanocoatings are an important research direction for dental research and are subject to further study.

2. Background

2.1 Implant material

a. Metal

When selecting the implant material, various factors need to be taken into account that influence the choice. Reference to specific parameters of the implant includes the mechanical properties and chemical composition of the material. A good implant material should be biocompatible and have strength, durability and resistance to corrosion and resistance. In addition, the biological response of the implant material should be considered. The most common and most widely used materials are metals, ceramics and polymers. In the early days, gold, silver, aluminum and platinum were used. These are now being replaced by metals, ceramics, and polymers[23][24].

b. Ceramics

The discovery and use of ceramics in implant medicine was made due to the need to overcome the biological problems of metals (e.g. titanium). The most widely used material in ceramics is plasma sprayed hydroxyapatite. In the event of implant medicine it can be found that zirconia is the most effective material for dental implants[25].

Advantages and disadvantages of zirconia

(1) Advantages:

Zirconia is compatible with human tissue.

Zirconia has high strength and good resistance to fracture.

Zirconia tolerates wear and corrosion relatively well.

(2) Disadvantages:

The material deteriorates after prolonged use.

It has been proven that zirconia implants may have a higher failure rate compared to titanium[26].

c. Polymers

Unlike metals that can produce microwave or electrolytic currents, polymers exhibit fibrous connective tissue adhesion.

The following polymeric materials are commonly used in implant medicine, Polymethyl methacrylate, etc[27].

In addition to this, various problems such as allergic reactions, implant fracture, biomechanical overload, etc. can occur during the actual treatment process after implant installation. These problems are to be overcome by exploring the experiments and selection of materials to be discussed in further studies.

2.2 Different surface modification methods

a. Chemical methods

Chemical methods can be used to modify the surface of the powder particles by using functional groups in organic molecules to chemically react with the filler surface and coat the surface of the particles. In the field of implant medicine, this can be done with the help of acids and bases, and common chemical modification treatments are anodization and chemical vapor deposition. Figure 1 below shows an electron micrograph of an implant surface treatment obtained by oxidation.

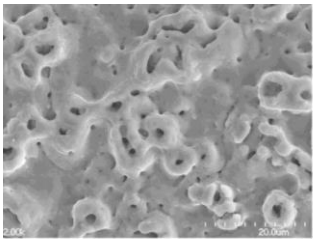

Figure 1: Scanning electron microscope image of a representative oxidation-treated implant surface

b. Etched surfaces

In the case of titanium and titanium alloys as the material of choice for implants, experimental treatments can use strong acids not only to improve the roughness but also to remove the oxidized layer of the implant. The use of acid-etching solutions mixed in specific ratios allows to achieve an increase in surface area, which enhances the bone reaction and reduces inflammation [28].

c. Sandblasted and acid etched surfaces

Acid etching treatment is the method of using acid to corrode metal and get special effect. In the specific operation, the corrosive solvent such as nitric acid is mostly used for treatment. In order to achieve the design effect that part of the surface of the plated part is corroded and part is retained, acid etching treatment is mostly used in conjunction with corrosion-resistant materials. Implants are produced by sandblasting and acid etching of large grit grains of about 250-500lm to produce a special implant surface. During the healing process in the actual medical procedure it was seen that after 4 weeks the fit of the two surfaces became identical. It was thus concluded that the sandblasting and acid-etching surface treatment methods are effective and feasible in the actual healing process. [29].

2.3 Properties of nanoparticles in dentistry

a. Antimicrobial activity of nanoparticles in dentistry

The antibacterial activity of nanoparticles is reflected in the fact that the specific surface area increases greatly as the particle size of the substance decreases [30]. The volume percentage of the surface is 50% for particles with a particle size of 5 nm, and increases to 80% at a particle size of 2 nm. The huge specific surface, the bond state is severely mismatched, and many active centers appear, making the nanomaterials have an extremely strong adsorption capacity, thus having the ability to adsorb for both oxygen atoms, oxygen radicals, and bacteria that contribute to the decay of substances, making them antiseptic and antibacterial. Among them, the antimicrobial ability of nanoparticles for bacteria in dentistry is shown in Table 1 below.

Table 1: List of some nanoparticles antimicrobial activity in dentistry

Material	Properties	Application
Copper coted metal	Offer antimicrobial properties	Denture framework
Copper nanoparticles incorporated in glass	Offer antimicrobial properties	Glass Ionomer restoration
Nano copper-nonstoichiometric dicalcium silicate	Offer antimicrobial properties, Facilitate tissue regeneration	Regenerative dental material
Nickeltitanium -copper alloy	Offer Antimicrobial Properties	Orthodontic bracket
ZnO-containing light-cure glass ionomer	Improve antimicrobial activities against	Restorative dentistry

In addition, metal ion dissolution in the form of Ag +, Cu 2+, Zn 2+, etc. with strong oxidizing ability, destroy the metabolic effect of bacterial cells, prevent the reproduction of microorganisms, so as to achieve antibacterial and anti-inflammatory effect. When the bacteria are killed, Ag + will be free again to interact with other bacteria to carry out a new round of killing, until the bacteria are all killed.

The ion release is directly related to the antibacterial activity of nanoparticles [31].

Nanoparticles are commonly used in biomedicine and can act as an effective antimicrobial agent. They are able to slow down or stop the growth of microbial resistance due to their mode of action which interacts directly with the bacterial cell wall and targets several different biomolecules at the same time. Recent studies have shown that the incorporation of antimicrobial nanoparticles can greatly facilitate the treatment of primary and non-primary dental diseases.

b. Restorative nanoparticles in dentistry

Restorative materials often fracture due to the accumulation of biofilm, secondary caries and other factors. This causes biofilm, secondary caries, and mass fracture disorders[32]. To aid in the selection of the most appropriate restorative material, a study was conducted to examine the stress distribution in implants after loading. The results showed that materials with a high modulus of elasticity relative to the stress level can reduce the stress level in the abutment, implant and peri-implant bone. Most implant failures can be avoided with careful treatment planning and knowledge of the restorative function of the implant. Dental Implants In cases of overbite and dysfunction, the restorative material used is an important determinant and can have a positive or negative impact on these problems. These problems can have both positive and negative effects. They can also protect the bone tissue from damage, since the behavior of the bone is proportional to the magnitude of the load [33].

2.4 Types of nanocoatings in dental implants

Nanotechnology is gaining interest in implant medicine due to its own superior properties. Nanotechnology is used to modify the surface quality of synthetic implants in order to improve their bioactivity and reliability. For this purpose, nanomaterials and nanocomposites are being surface treated. To achieve this goal, modern coatings combining such inorganic and biological components (e.g., proteins and peptides) are being investigated and applied [34]. At the same time, nanocoatings can be used to prevent the release of harmful or excessive metal ions and to create conditions and structures suitable for new bone formation. In dental implants, the coating procedure is one of the most reliable and proven conventional treatment methods.

a. Calcium phosphate nano-coating

A popular option among many is to cover the implant with a calcium phosphate nano-coating. As a non-inflammatory and non-immune substance, the mineralizing effect of calcium phosphate nanoparticles improves the organic matrix. Calcium phosphate nanoparticles are a durable, natural form of calcium phosphate. Four traditional industrial coating processes have been used to produce bioactive hydroxyapatite coatings over the past three decades.

b. Biogenic coating

Bone morphogenetic proteins (BMPs), liposomes and other molecules can be used in combination with calcium phosphate coatings for better therapeutic healing and may continue to play an important role in enhancing osseointegration of dental implants. It may be possible to enhance osseointegration of dental implants at a faster rate [34].

c. Nanocoatings derived from sol-gel

The liquid is attractive and practical because it can be used for the chemical synthesis of ceramic coatings such as hydroxyapatite. Complex geometries can be covered and the process is very simple. In addition, sol-gel coatings have been shown to be effective in enhancing the success and healing period of dental implants [34].

d. Nanocomposite coating

Nanocomposites and nanocomposite coatings are usually made of two or more materials. The matrix consists of biocompatible polymers, metals and ceramics. The inclusion of secondary nanoparticles makes them more similar to real bones. Mechanical property analysis reports conclude, for example, that the strength and modulus are close to those of real bones. A new generation of nanocomposite coatings and bioglasses is being developed to enhance osseointegration. Figure 2 below shows an electron microscope photograph of an organic composite coating employing nanostructures that can effectively aid the bone regeneration and bone healing process.

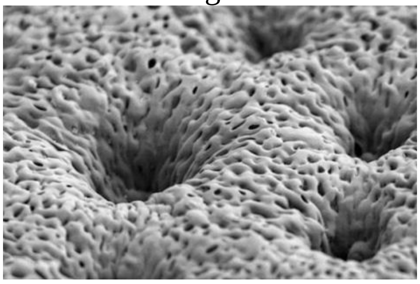

Figure 2: Scanning electron microscope images of water permeable nanostructures under carboxyacetate copolymer film coatings

3. Nanoparticle applications within implant dentistry

The survival rate of dental implants is about 95% and quite predictable according to clinical studies over a 10-year period [35]. Despite the positive clinical results, there are still difficulties with the mechanical, biological and functional aspects of the implants. Peri-implantitis is a major complication that can lead to bone loss around the implant and ultimately to implant failure. Postoperative readmission studies in real patients have shown that peri-implantitis occurs within 5 to 10 years after implant placement. In more than 20% of patients and 10% of implants. The most commonly used nanoparticles in dentistry are zirconium dioxide, copper oxide and titanium dioxide. These nanoparticles are less harmful and more effective against bacteria than other metal oxide nanoparticles such as AgO/AgO2.

3.1 Copper nanoparticles

Copper has long been used as an antibacterial and anti-inflammatory agent. In addition, CuNPs have been used to improve the bioactivity and antimicrobial properties of titanium-tan alloy dental implants [36].

3.2 Titanium nanoparticles

Titanium is widely used in medicine and dentistry for its excellent corrosion resistance, low toxicity, very low allergenicity and biocompatibility, which makes it a high-performance material. A good biological response can be achieved in case of contact with living cells. In addition, titanium is very flexible and prone to corrosion. Polymeric materials tend to retain moisture and have a low mechanical (wear quality, strength), while ceramics are both hard and brittle. Due to their high biocompatibility and osseointegration, titanium and its alloys are the materials of choice today[37].

3.3 Silver nanoparticles

Peri-implant infections are a serious risk associated with implant treatment. Since the risk of infection persists for a long time after surgery, this potential risk cannot be treated with conventional antimicrobial techniques [38]. Given the safety and powerful antimicrobial properties of silver nanoparticles, modification of implant surfaces with silver nanoparticles is possible, and modification of implant surfaces using different doping techniques is currently receiving a lot of attention [39]. At low concentrations, silver nanoparticles can eradicate Staphylococcus aureus without significantly affecting other bacteria or severely damaging osteoblasts [40].

3.4 Zirconium nanoparticles

Zirconium is widely used for dental implants and nanoscale tissue engineering. Zirconia is used in many applications due to its better mechanical properties and higher biocompatibility. Zirconia nanoparticles are widely used in a variety of applications for dental implants and tissue engineering due to their better mechanical properties and higher biocompatibility. Co-precipitation, hydrothermal methods Hydrothermal and sol-gel methods are used as the main methods for the production of ZrO2 nanopowders. Due to its inherent low magnetic susceptibility in the human environment compared to all implantable metals (including titanium), zirconium is due to the presence of titanium and the formation of a bone-like apatite layer. Due to its excellent metallic properties, its recent high interest from industry scholars, zirconium alloys have recently attracted increasing interest as an alternative material for implants.

3.5 Zinc nanoparticles

Zinc metal has many potential properties, including electrical, optical and electromagnetic. Zinc oxide nanoparticles have been developed primarily to inhibit the activity of bacteria that cause dental caries and to improve the mechanical and structural quality of materials as well as their resistance to disease. Many studies have demonstrated the value of zinc oxide, and many studies have shown that zinc oxide nanoparticles as additives can improve the mechanical and structural quality of materials, as well as their antimicrobial properties.

4. Conclusion

Although a great deal of research has been done in the field of dental implantology regarding the surface treatment of implants, there are still many difficulties to be overcome in the future. The surface profile, surface modification techniques, etc. must be analyzed before the dental implant is placed. The key factors required for a successful dental implant are osseointegration, material selection, surface morphology, surface modification, etc. The advent of nanotechnology has led to increasing interest and dental implant research has focused on nanoscale modifications and use. Currently, there are several research gaps in the clinical use of nanoengineered dental implants. Although many nanoengineering approaches have shown great promise in enhancing the bioactivity of dental implants. The results of previous studies, experimental data and clinical treatments show that titanium and zirconia are among the most stable materials and that a better surface modification method is sandblasting, but of course the most promising development and research is the study of nanomaterials for the surface treatment of dental implants. Undoubtedly, there are many options for dental implants. However, it is still a little difficult to choose the best from them. The much talked about nano-engineered implants have multiple therapeutic effects, by mixing different drugs or by incorporating nanoparticles made of metals or biopolymers. Agents, better therapeutic results can be achieved in patients of advanced age or with osteoporosis. There is still an information gap around the biological mechanisms that trigger osseointegration, and there is a need to create specific guidelines for setting standards for dental implants. What kind of response will occur with the material. What is the range of the material? Will it last for a long time? All deserve further and more in-depth research and exploration.

In terms of cytotoxicity, the key to using nanomaterials in dental implants is to identify and control the release of metal ions and nanoparticles in order to improve the therapeutic effect of the implant. Improving the therapeutic effect of implants.Since then, Hager has always conducted research related to custom implant medicine, using 3D printing related technology for implant placement and follow-up treatment according to the individual requirements of the exchange. Biocompatibility and osseointegration play an important role in dental implantology. In order to effectively design specialized implants for the treatment of on-site bone problems around dental implants, a better understanding of the in vivo bioreactivity of the clear implant-bone interface is required. Currently, the importance of inflammatory and blood clot cells in the development of instructive bone implants has been generally overlooked as they can initiate a focused bone healing response in challenging situations. Nanomaterials have received high attention for surface treatment of implants, and several types of metal nanoparticles have received significant attention due to their excellent mechanical properties of mechanical properties, high surface-to-volume ratio, ability to stop crack propagation, and higher fracture toughness. Nanocoatings are available in many forms and are an important future development in dental research. Further exploration by the industry's research eye is yet to be done in order to create the best dental implants using nanotechnology.

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