The Study of PEEK Composites as the Dental Implant Materials

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***Abstract*—Polyetheretherketone (PEEK) is a kind of synthetic thermoplastic polymer, because of its good biological compatibility, chemical stability and radiolucency, it has been widely used in the field of medicine. Compared with the titanium, the elastic modulus of PEEK is closer to human cortical bone, PEEK could be a viable alternative material for dental implants. Nevertheless the inherent bio-inert nature and lower osteogenic activity limit its wider clinical applications, thus a considerable effort has been made to improve its biological properties. This article makes a summary on the research progress of the application of PEEK composites in dental implant.**

***Index Terms*—PEEK; PEEK composites; biological properties**

I. Introduction

With the acceleration of human aging, the development of implant materials for human body is becoming more and more important. It is the frontier and hotspot of biomedical materials research to find better bone defect repair materials for patients to reconstruct health. There are three ways to repair bone defects: self-repair, autologous bone repair and allogeneic biomaterial restoration. Self-repair can only be made in the case of small defects, using the regeneration ability of bone tissue itself. The best way to treat defects that can not be self-repaired is to use autologous bone graft. However, autologous bone transplantation has some problems, such as limited source, easy to cause infection, low survival rate of bone flap, secondary injury to patients, and it is impossible to take a large number of bone[1]. Bone cement and titanium alloys are widely used in allogenic biomaterials. The elastic modulus of titanium and titanium alloy is 110 GPa, which is much different from the elastic modulus of 3-18 GPa of human bone tissue, and the load can not be uniformly transmitted to the surrounding branches through the implant. Holding tissue produces stress shielding effect, which leads to bone absorption and implant shedding, and is not conducive to long-term survival of implants[2].

With the improvement of people's living standard, oral health has attracted more and more attention. Dental and dentition defects caused by dental caries, tooth trauma, periodontal disease and other causes are common and frequently-occurring diseases in stomatology, seriously affecting the oral tissue and the overall health of patients. Dental implant repair has become one of the best methods for the restoration of missing teeth. Oral materials are widely used as a semi implanting biomaterial. Metal and alloy materials have good mechanical properties and certain biocompatibility, and have been widely used in dental restorations, implants and other materials. Titanium and titanium alloys are the basic materials in dental materials, but there are also some problems. For example, after implantation of titanium or titanium alloy implants, metal ions will penetrate into gingival tissue, affect the metabolism of melanocytes, so that melanocytes enter the surface structure of gingival tissue, causing gingival discoloration and even serious inflammatory reaction[3]. Because the elastic modulus of titanium and its alloy is 6-20 times of the surrounding bone tissue, when the implant is loaded, the stress can not be uniformly transmitted to the surrounding bone tissue, resulting in the "stress shielding" effect, leading to the atrophy of bone tissue around the implant, implant loosening and falling off, and ultimately leading to implant failure. Therefore, the research and development of implant repair materials with excellent mechanical properties and biocompatibility has important clinical significance.

PEEK is a kind of high molecular polymer with excellent biocompatibility, light weight, non-toxicity, strong corrosion resistance, and is the closest implantable material to human bone. PEEK has been designated as the best bone graft material, and has been recognized by FDA. PEEK is widely used in non-metallic implants, such as spinal implants, artificial bones and wound repair, because of its good radio transmittance. There is no need to remove it in clinical X-ray, MRI and CT examinations, and because of its elastic modulus between cortical bone and cancellous bone and good dimensional stability. In the field of stomatology, it is mainly used in dental implant healing cap, temporary abutment and occlusal rod in orthodontic treatment [4].

The current research focuses on the surface modification of PEEK and its composites. Surface

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treatment methods can be divided into two categories: surface coarsening and surface modification. Surface roughening mainly includes acid etching, sand blasting and so on. Surface modification mainly includes silane coupling, coating and plasma treatment.

II. Surface modification of PEEK

A. Sandblasting

Current research shows that sandblasting is the most direct method to improve the surface roughness of materials, and can effectively change the surface morphology of materials. Sandblasting treatment can clean pollution, form a rough surface with locking effect, produce micro-retaining configuration, increase mechanical bonding force, thus forming a locking connection. For the surface to be treated with different hardness, if the granularity of sand is too small, the surface roughness will be insufficient; if the granularity of sand is too large, the surface will be peeled off, and the interfacial stress concentration or roughness will be reduced due to the roughness. Sandblasting can effectively change the surface morphology of materials. For dental implants, the more rough the surface, the easier to promote bone healing. The particle size, duration and angle of sandblasting all affect the surface morphology of materials [5]. The smaller the diameter of sandblasting powder, the more obvious the change of material surface morphology, the higher the osteogenic efficiency; therefore, reasonable use of sandblasting technology can effectively improve the biological activity of materials, improve the osteogenic efficiency of materials. In order to explore the effect of sandblasting on the biocompatibility and bone-to-implant ratio (BIC) of nano-fluoroapatite polyether ether ketone (PEEK) composites, the bone-to-implant ratio (BIC) and bone-to-implant ratio (BMI) were measured by implanting PEEK composites with and without sandblasting. And mineral apposition rate (MAR). The results showed that surface sandblasting could enhance the initial stability of PEEK implants and improve the osteogenesis of PEEK implants.

B. Coating

Titanium dioxide layer can promote the aggregation, proliferation and differentiation of osteoblasts on the surface of materials [6]. Some scholars prepared a layer of titanium dioxide film on the surface of PEEK material and implanted the materials of experimental group and control group. In vivo, bone remodeling around the coating material was significantly increased compared with the control group, which significantly improved the osteogenic efficiency of PEEK [7]. In addition to titanium dioxide coating, silicon dioxide, alumina, nano-hydroxyapatite and other coatings were also prepared on the surface of PEEK, which improved the osteogenic properties to a certain extent, and provided a basis for the application of PEEK in oral implant field.

C. Laser processing

In recent years, femtosecond laser has been widely used to improve the surface properties of various materials. Unlike other treatment methods, femtosecond laser etching can form a uniform, regular three-dimensional structure on the surface of implanted materials, and the surface modification layer is thin, has little effect on the substrate, and the resulting surface oxide layer and the substrate bond. Close together, overcome the shortcomings of the existing modification methods. Compared with ordinary laser, femtosecond laser has the advantages of short pulse time, high instantaneous power and no pollution to materials. It is a high efficiency and high precision surface treatment method of materials, so it has been applied in many special fields by scholars. Femtosecond laser can effectively improve the bioactivity of titanium implants [8]. Cunha [9] treated PEEK with femtosecond laser and observed the surface morphology of PEEK by atomic force microscopy. It was found that femtosecond laser can construct periodic nano-structures on the surface of PEEK. Femtosecond laser can effectively improve the bioactivity and osteogenic efficiency of materials.

D. Plasma treatment

PEEK belongs to semi-crystalline organic polymer materials, and has excellent physical and chemical properties such as high temperature resistance, high pressure resistance. Therefore, plasma surface modification can not only affect its excellent properties, but also obtain certain osteogenic activity. The surface treatment of PEEK by plasma can produce erosion on the surface of PEEK, which is mainly due to the physical erosion of electrons and ions impacting on the surface of PEEK by plasma, or the chemical erosion of PEEK by chemical active substances. Plasma sputtering erodes the surface of the treated material to form a large number of protrusions, coarsens the surface of the material, enlarges the contact area of the material, thus improving the osteogenesis efficiency. Plasma spraying is an innovative method for surface modification of modified materials. Briem D et al [10] co-cultured fibroblasts and osteoblasts with plasma sprayed PEEK on the surface. Plasma-modified PEEK can improve its biocompatibility and promote the combination of implants and bone.

E. Chemical acid etching

The chemical etching of PEEK with acid solution can remove the oxide film on the surface of PEEK, increase the roughness and specific surface area of PEEK, make the surface of PEEK have higher surface free energy and wettability, and is more conducive to the aggregation and proliferation of osteoblasts on it, thereby improving the osteogenesis efficiency of PEEK. The implant is stable in the jaws and functions. Some scholars have soaked PEEK in Potassium Permanganate containing phosphoric acid solution for 30 min and etched PEEK by chemical etching. The results show that the contact angle and surface energy of untreated PEEK with aqueous solution are lower than those of chemical etching PEEK. The higher the surface energy, the better the biological activity, the more conducive to osteoblast aggregation and proliferation, the higher the osteogenic efficiency [11].

F. Antibacterial modification

PEEK, as an oral implant, is prone to inflammation after implantation, which limits its wide clinical application. Therefore, the development of antibacterial PEEK composites has become another hot topic of concern. Antibacterial agents are generally divided into inorganic antibacterial agents, organic antibacterial agents and natural antibacterial agents. Silver ions are widely used inorganic antibacterial agents at present. Silver has a broad spectrum of antimicrobial effects, and has a strong bactericidal effect on Gram-positive and gram-negative bacteria, and this effect lasts for a long time. Nano-silver ion has stronger bactericidal ability than silver ion because of its large surface area ratio and long-term release ability of silver ion. Therefore, the preparation of nano-silver coating on PEEK surface can improve its antibacterial properties, reduce the incidence of peri-implant inflammation, and improve the success rate of implants. Titanium oxide is also a good antibacterial agent. Some scholars have studied the antibacterial properties of titanium oxide coatings combined with different concentrations of silver. The results show that titanium pentoxide combined with 12.5% silver coating has a good antibacterial effect on Staphylococcus aureus and good biocompatibility [12].

III. OUT LOOK

PEEK composites are expected to be widely used as prosthodontics and implants in the near future due to the excellent properties of PEEK and its composites and the continuous development and progress of processing technology and material processing technology. With the advancement of materials science and technology, the biological activity and mechanical properties of PEEK and its composites are constantly improved, and its application prospect is immeasurable. We should adjust the properties of implant materials to make PEEK and its composites have better compatibility and become the best oral implant materials.

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REFERENCES

[1] Silber J S, Anderson D G, Daffner S D, et al. Donor site morbidity after anterior iliac crest bone harvest for single level anterior cervical discectomy and fusion. *Spine*, 2003, 28(2):134-139.

[2] Li X, Feng Y F, Wang C T, et al. Evaluation of Biological Properties of Electron Beam Melted Ti6Al4V Implant with Biomimetic Coating In Vitro and In Vivo[J]. *Plos One*, 2012, 7(12):e52049.

[3] Sakai T, Sakai H, Hashimato N. Gingival pigmentation beneath ametallic crown: electron microscopic observation and energy dispense analysis. *Oral Pathol*, 1998, 17(8): 409-415.

[4] Feerick EM, Kennedy J, Mullett H, et al. Investigation of metallic and carbon fibre PEEK fracture fixation devices for three-part proximal humeral fracture. *Med Eng Phys*, 2013, 35(6): 712–722R.

[5] Ourahmoune R, Salvia M, Mathia TG, et al. Surface morphology and wettability of sandblasted PEEK and its composites. *Scanning*, 2014, 36 (1): 64-75.

[6] Sugita Y, Ishizaki K, Iwasa F, et al. Effects of picoto-nanometer-thin TiO2 coating on the biological properties of microroughened titanium. *Biomaterials*, 2011, 32 (33): 8374-8384.

[7] Wu X, Liu X, Wei J, et al. Nano-TiO2/PEEK bioactive composite as a bone substitute material: in vitro and in vivo studies. *Int J Nanomedicine*, 2012, 7:1215-1225.

[8] Tan K H, Chua C K, Leong K F, et al. Scaffold development using selective laser sintering of polyetheretherketone-hydroxyapatite biocomposite [J].*Biomaterials*, 2003, 24 (18): 3115-3123.

[9] Cunha A, Serro A P, Oliveira V, et al. Wetting behavior of femtosecond laser textured Ti 6Al 4V surfaces. *Face Science*, 2013, 265: 688-696.

[10] Briem D, Strametz S, et al. Response of primary fibroblasts and osteoblast to plasma treated polyetheretherketone (PEEK) surfaces. *J Mater Sci Mater Med*, 2005, 16 (7): 671-677.

[11] Hacking SA, Harvey EJ, Tanzer M, et al. Acidetched microtexture for enhancement of bone growth into porous-coated implants. *J Bone Joint Surg Br*, 2003, 85(8):1182-1189.

[12] Huang H L, Chang Y Y, Chen H J, et al. Antibacterial properties and cytocompatibility of tantalum oxide coatings with different silver content. *Surface & Coatings Technology*, 2014, 259(2):193-198.