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 low 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

PEEK is a kind of synthetic semi-crystalline aromatic organic polymer that exhibits outstanding properties, such as: antioxidant, high strength, high thermal stability, good fatigue resistance, excellent processing performance and reasonable biocompatibility. It has been successfully applied in aerospace, automotive, chemical manufacturing and medical field. The material of choice for oral endosseous implants is pure titanium, introduced at the end of the 1960s by Branemark. Although this argument is well evidence-based, it was demonstrated that their use can be correlated with a range of problems. One problem is a potential hypersensitivity to titanium; another problem could occur due to the gradient difference in the elastic modulus of a titanium implant and its surrounding bone, this may cause stress in the implant-bone interface during load transfer, probably resulting in peri-implant bone loss, eventually lead to implant loosening and shedding [1,2]. Also, titanium can cause esthetic problems due to its lack of light transmission. Additionally, an increasing number of patients are demanding dental reconstructions of completely metal-free materials [1]. PEEK is a kind of non-metallic material and has elastic modulus similar to bone, so compared with titanium, PEEK can be used as a new type of dental implant material. Although PEEK has a wide range of advantages, the inherent bio-inert nature hinder its good combination with surrounding bone, finally limits its wider clinical applications, so people used lots of methods to improve its biological properties. In this article, the research of PEEK composites as the dental implant materials is reviewed.

The PEEK composites were classified into two kinds by the size of the impregnating bioactive materials: the conventional PEEK composites and the nano-sized (<100nm). Conventional PEEK composites include carbon fibre-reinforced PEEK (CFR-PEEK), glass fiber-reinforced PEEK (GFR-PEEK), hydroxyapatite/PEEK (HA/PEEK), strontium-containing hydroxyapatite/PEEK (Sr-HA/PEEK). Nano-sized PEEK composites include Nano-TiO2/PEEK (n-TiO2/PEEK), Nano-Fluorineap-atite (n-FA/PEEK), Nano-hydroxyapatite/PEEK (n-HA/PEEK).

II. TYPES OF PEEK BIO COMPOSITES

A. CFR-PEEK

Carbon fiber is a kind of linear material with a special size effect from several microns to tens of microns. As an important reinforcement material, carbon fiber has been widely used in many fields. CFR-PEEK has the advantages of high strength, low modulus of elasticity (similar to bone) and so on, which make it great potential in human bone tissue repair and implant materials. CFR-PEEK is beneficial as an implant material, since it appears to stimulate osteoblast protein content, without inhibiting that of fibroblasts, neither material appeared to cause any alteration in osteoblast morphology [3]. In vitro study on CFR-PEEK found that: CFR-PEEK not only has good mechanical properties and biocompatibility, but also can adapt to the mechanical requirements of the bone defects. Mandible stand the force produced by chewing movement, after the bone defect was repaired, the mechanical properties of the bone were not well adapted to the mechanical requirements of the mandible due to the mechanical properties of the implant material, which could easily lead to loosening of the implant materials [4]. However, CFR-PEEK has an elastic modulus similar to that of normal human cortical bone, the probability of occurrence of the above problem was significantly reduced when the CFR-PEEK as the implant material.

B. GFR-PEEK
Glass fiber has the advantages of high elastic modulus, high strength, good thermal stability and stable expansion coefficient. GFR-PEEK is made up of PEEK and 10% glass fibers with diameters ranging from a few microns to tens microns and GFR-PEEK has elastic modulus similar to bone. Above all, it can promote the proliferation and differentiation of MG-63 cells. In vitro studies showed that GFR-PEEK can provide a suitable environment for the formation of osteocalcin [5]. This can promote the bone formation process, so that GFR-PEEK can form a good combination with surrounding bone, which can improve the success rate of oral implants.

C. HA/PEEK

HA is a kind of inorganic material, which is the main component of inorganic substance in human bone tissue. Khor et al. [6] made HA/PEEK composites by compounding, granulating and injection molding technique, the particle size of HA is 3~100 micron. Experiment find that when the volume fraction of HA was 30%, it has elastic modulus similar to human cortical bone. Zhang et al. [7] used the selective laser sintering (SLS) technique to make HA/PEEK composite, the particle size of HA is 3.80 micron. Experiment revealed that the composite can promote the growth of osteoblasts, and with the increase of HA content, the degree of proliferation and differentiation of osteoblasts will increase accordingly. Yu et al. [8] prepared HA/PEEK composite by mixing, compaction, and pressureless sintering process and evaluated the bioactivities of HA/PEEK composites with 10 vol%, 20%, 30 vol% and 40 vol% HA by immersing the composite disks in SBF, finding that with the increase of HA volume fraction, the time of formation of bone like apatite will decrease, the result showed that the biological activity of the composites increased with the increase of HA content. Prepare HA/PEEK composites by injection molding, the amount of HA incorporated into the PEEK polymer matrix ranges from 5 to 40vol%, the particle size of HA is 25.68 micron. Experiment find that when the volume fraction of HA was 20%-30%, the elastic modulus of the composite is 5-7Gpa, which is similar to the human cortical bone. In addition, the HA/PEEK composite with a volume fraction of 20% was implanted into the femur of the pig, which proved that the composite has good bioactivity and biocompatibility [9].

D. Sr-HA/PEEK

Strontium is a biologically active element, which can promote the adhesion and mineralization of osteoblasts, induce bone formation and reduce the risk of bone fracture. Sr-HA/PEEK composites were successfully fabricated with 15~30 vol% Sr-HA filler reinforcement using compression molding with the particle size of 43.34±0.08 micron. The Sr-HA/PEEK composite was proven to outperform HA/PEEK in providing bioactivity. More apatites were formed on the surface of Sr-HA/PEEK composite than HA/PEEK composite indicating that Sr-HA/PEEK offer better bone-bonding ability than HA/PEEK composite. More bone-like nodules were formed on the Sr-HA/PEEK composite than HA/PEEK composite, which indicated that strontium can stimulate more bone mineralization. It can be seen that the Sr-HA/PEEK composite not only inherit the good mechanical properties of PEEK, but also have stronger biological properties [10].

E. n-TiO2/PEEK

TiO2 has good biocompatibility, bioactivity and is hydrophilic, the preparation of n-TiO2/PEEK composite by integrate n-TiO2 with PEEK can significantly improve the biological activity of PEEK. Wu et al. [11] fabricated the n-TiO2/PEEK composite by powder mixing and compression molding methods, the amount of n-TiO2 in the n-TiO2/PEEK composite was 40 wt%. The results showed that n-TiO2 could promote the adhesion and proliferation of osteoblasts, and when the composite was implanted into the tibia of the Beagle dog, it was found that it could significantly promote bone regeneration around the implant compared with the pure PEEK implant, indicating that n-TiO2 significantly improves the biological activity of PEEK. Tsou et al. [12] found that the nano-TiO2/PEEK composites had higher osteoblast compatibility.

F. n-FA/PEEK

Metal and polymer implants are susceptible to bacteria during the implantation, eventually lead to implant infection or implant failure, which is one of the most serious complications of implant surgery. Therefore, when we select bone implant materials, not only good mechanical properties and biocompatibility but also antibacterial properties of the material should be taken into account. The fluoride ions from the n-FA can affect the energy metabolism and enzyme activity of the bacteria, so n-FA/PEEK composite have antibacterial effect [13]. n-FA was incorporated into PEEK to improve the performance of the new n-FA/PEEK composite, and to explore its biocompatibility and osteogenesis in vivo. The result showed that wound healing was good and no implants removal [14]. The rate of bone mineralization deposition is one of the important parameters of bone dynamics, which is the most commonly used measure of bone remodeling rate. The rate of bone mineralization deposition of n-FA/PEEK was significantly higher than that of PEEK. Fluoride ion inhibits the activity of osteoclast and phagocye and stimulate new bone formation [15].

G. n-HA/PEEK

Due to the low physical bond energy between PEEK and HA, the mechanical properties of the HA/PEEK composites were decreased compared with that of pure PEEK. However, when n-HA was added into PEEK to prepare n-HA/PEEK composite, the composite had good mechanical properties and high bioactivity [16]. Because of the debonding between the HA filler and the PEEK matrix, the conventional HA/PEEK composites cannot bear the long-term critical loading, but nanotechnology can solve this problem partially. Wang et al. [17] prepared HA/PEEK nanocomposites by a compounding and injection molding process, they found that this novel
HA/PEEK nanocomposite exhibited satisfactory mechanical properties. More importantly, no debonding occurred between the well-dispersed HA nanoparticles and the PEEK matrix. A nanocomposite of PEEK with 10 wt% HA was produced by extrusion and injection molding and particle size of HA is less than 100 nanometer. It was found that the composite could promote the proliferation of human adipose stem cells (hASCs) compared with PEEK [18].

III. OUTLOOK

The biological properties of PEEK were greatly enhanced by the preparation of PEEK composites, so the prospect of PEEK and its composite materials in the field of oral implant materials is immeasurable. With the progress of materials science, it is possible to improve its biological properties through a variety of ways to make it more widely used in oral clinic.

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