

Progress in the study of polyetheretherketone (PEEK) as a removable partial denture scaffold material

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Abstract: Removable partial dentures are still widely used to repair dental defects. Due to the problems of aesthetic defects, heavy weight, and metallic odor of metal removable partial dentures that are widely used in clinical practice, non-metallic alternative materials are now actively explored. As a new material with good physical and chemical properties, polyether ether ketone (PEEK) has been tried to be used in the fabrication of removable partial dentures. In this paper, we review the current status of research on the application of PEEK for the fabrication of removable partial dentures.

1. Introduction

Tooth loss is a common and frequent disease in clinical restorative dentistry, which has a serious impact on the quality of life of patients. Missing front teeth can directly affect the aesthetics and pronunciation accuracy of the patient's face, while missing back teeth can affect the patient's chewing efficiency, thus affecting the patient's gastrointestinal health and leading to a series of digestive system diseases [1] The missing teeth can affect the efficiency of chewing, thus affecting the patient's gastrointestinal health and leading to a series of digestive diseases. Tooth loss severely affects the patient's speech and chewing function, while seriously impairing the patient's aesthetics and causing a drastic decrease in the patient's quality of life.[2,3] The quality of life of patients has been drastically reduced. As China enters an aging society, the number of patients with tooth loss is increasing, and the oral health of middle-aged and elderly people has also aroused widespread concern, and the concept that oral health is the foundation of whole-body health is gradually accepted by the public.

2. Application of removable partial dentures

The restoration methods of tooth loss include fixed partial denture, removable partial denture, combined fixed-mobile denture, and implant denture. With the development of fixed denture and implant denture, the concern for removable partial denture for restoration of tooth loss has decreased; however, due to the limitations of patient physiology, oral anatomy and economic

conditions, removable partial denture is still widely used in clinical practice.[4] . Compared with fixed partial denture or implant restoration, removable partial denture

The denture has a wider range of indications and is more flexible in design, and is often used to restore dental defects, especially in elderly patients.[5] The results of the Fourth National Dental Epidemiological Survey (NDEES) show that among patients aged 65-74 years with dental defects, the number of patients with dental defects is about 1,000. The results of the Fourth National Oral Epidemiological Survey showed that 0.3% of patients aged 65-74 with tooth loss chose implant restorations, 26.3% chose fixed prostheses, and 20.4% chose removable partial prostheses. This shows that removable partial denture is still one of the most important restorative options for edentulism[6] This shows that the removable partial denture is still one of the most important restorative options. Although the basic principles of removable partial denture (RPD) design are the same, the development of framework materials is still under investigation. Research is focused on the use of new materials to address the shortcomings of the alloys currently used in removable partial denture fabrication [2].

3. Commonly used materials for removable partial denture brackets

Conventional removable partial denture bracket materials can be broadly classified into metallic and non-metallic categories. The metallic category includes cobalt-chromium alloy, pure titanium, Vitallium, etc. The non-metallic denture bracket materials include a large number of organic polymers, but their mechanical and mechanical properties, wear resistance and comfort are again limited. The dental industry is always looking for better materials to compensate for the shortcomings of existing materials. Polyether ether ketone (PEEK) is widely used in the medical field due to its reliable biosafety, elastic modulus close to that of bone and excellent corrosion and creep resistance.[7] PEEK has been widely used in the medical field due to its reliable biosafety, elastic modulus close to that of bone, and excellent corrosion and creep resistance.

3.1 Cobalt-chromium alloy

Cobalt-chromium alloy is the main restorative material used to make bracket denture, which has the advantages of high retention, stress resistance, and low cost. Some studies have shown that cobalt-chromium alloy requires only 0.25 mm of recess depth to provide good retention, but the limitations of the material properties often make the cast brackets have the disadvantages of large volume, little variation in the design of the abutment, poor snap ring resilience[8] However, due to the limitations of the material, the cast brackets have the disadvantages of large volume, little variation in the design of the abutment, poor resilience of the retaining ring, easy corrosion in long-term saliva immersion, and poor biocompatibility, which can easily lead to oral mucositis and periodontitis in patients restored with this material.[8-11] The use of this material can easily lead to oral mucositis and periodontitis after restoration.

3.2 Pure titanium

Pure titanium has lower density, high elasticity, lighter mass, higher biocompatibility than cobalt-chromium alloy, and its surface titanium dioxide (TiO₂) oxide film is tightly bound to the peptide, forming a high degree of anti-corrosion protective layer film, which prevents material corrosion.[9] However, pure titanium casting process is easy to produce porosity and complex production process, easy to deformation of stress concentration parts, resulting in reduced retention force and even snap ring breakage.[12] However, the casting process of pure titanium is prone to porosity and complicated fabrication process, which may lead to deformation in the stress

concentration area, resulting in reduced retention and even fracture of the retainer. The application of pure titanium bracket material in the restoration of patients with dental defects can improve the chewing efficiency and satisfaction of restoration, as well as reduce the incidence of complications, and its effect is better than that of cobalt-chromium alloy bracket material restoration.[13] The results are better than those of cobalt-chromium brackets.

3.3 Vitallium

Vitallium is a high cobalt-chromium-molybdenum alloy that can be used for oral casting removable partial denture, which is based on the traditional cobalt-chromium alloy with increased chromium and molybdenum content. At present, there are 3 types of Vitallium in clinical practice: Vitallium, Vitallium2000 and Vitallium2000plus, mainly Vitallium2000 and Vitallium2000plus. The main components of Vitallium2000 introduced by Densberg include cobalt (60%), chromium (28%~32%) and molybdenum (5%~7%); Vitallium2000 is a cobalt-chromium high-temperature alloy with the same mechanical strength, oxidation resistance and thermal corrosion resistance as ordinary cobalt-chromium alloy, its stress resistance and elasticity are better, the bracket is not easily deformed, low fracture possibility, and the snap ring is easy to adjust. Low possibility, easy to adjust the snap ring[9] Moreover, the molybdenum material has the effect of anti-cariou[14] It can reduce the incidence of patient caries, periodontal disease and denture stomatitis, improve patient comfort and chewing power, and slow down the resorption of alveolar ridge.[15,16] Vitallium material has more advantages than traditional cobalt-chromium alloy and pure titanium, etc.[17] Lin Qing[1] The experimental study found that patients in the Vitallium 2000 group had a significantly higher rate of partial denture bracket seating after treatment than the cobalt-chromium and titanium groups, and a higher rate of satisfaction with comfort, speech and aesthetics than the other two groups.

3.4 Polyetheretherketone

Polyetheretherketone (PEEK) is a special engineering plastic with excellent performance, was first developed by ICI in 1978, China began its research and development in the 1980s. PEEK is a semi-crystalline organic polymer material, in recent years, due to its high temperature resistance, chemical corrosion resistance, radiation resistance, good biocompatibility and other good characteristics are widely used in aerospace, automotive manufacturing and precision instruments and other high-tech fields, automotive manufacturing and precision instruments.[18] As a member of the polyaryl ether ketone family. As a member of the polyaryl ether ketone family, PEEK is synthesized from bisphenol salts and aromatic dihalides through a nucleophilic substitution reaction. The benzene ring in the molecular structure gives PEEK rigidity, while the ether bond is tough enough to make PEEK highly resistant to stress. With excellent chemical stability, it not only avoids the release of toxic by-products, but also presents excellent biocompatibility. The many excellent properties have made it popular in the medical field, and it is currently used in orthopedic surgery, cardiovascular surgery, and other fields[19] .

As research progresses, PEEK and its compounds are attracting attention in the field of dentistry as a new dental material to replace traditional restorative materials.[20]

3.4.1 Good biocompatibility

Liu, Lijun [21] et al. concluded that PEEK materials have good biocompatibility through the analysis of acute systemic toxicity test, oral mucosal irritation test, and hemolysis test results. In animal tests, Liu Jun et al. examined the in vitro toxicity of PEEK by culturing mouse fibroblasts

and found that no cytotoxic reactions occurred within 96 h after cell exposure to PEEK; in addition, various systemic, intradermal, and intramuscular implantation studies of PEEK did not show toxicity or other adverse reactions, and genotoxicity tests also showed that PEEK was not teratogenic.[18] The genotoxicity test also showed that PEEK is not teratogenic.

3.4.2 Stable chemical properties

PEEK has good chemical stability, except for concentrated sulfuric acid, PEEK can withstand almost all chemical reagents although with 0.5% hygroscopicity, but can still be used under 200 °C steam for a long time, and can be used continuously at 260 °C high temperature.[20] PEEK can withstand almost all chemical reagents except concentrated sulfuric acid.

3.4.3 Physical properties

The modulus of elasticity of PEEK can be achieved by adding carbon fibers to achieve a similar 18 GPa as dentin and bone cortex. PEEK and its compounds have a high strength in addition to an ideal modulus of elasticity. In addition, PEEK has excellent creep resistance, heat aging resistance, and friction resistance.[20] PEEK is also less dense than metal and has no metallic odor. Compared with traditional cobalt-chromium alloy brackets, PEEK brackets are lighter in weight; because PEEK has good elasticity, the design of PEEK retainers with proximal mesiodistal brackets helps to relieve the distal stress on Class I abutment teeth; pure PEEK itself is tan in appearance and opaque, and its aesthetic effect cannot meet the aesthetic restorative requirements of the oral cavity if used directly. The existing commercial PEEK dental materials are mainly blended with appropriate proportions of metal oxides to change the color of the material.[22] Aesthetic problems can be solved by selecting a material that is compatible with the patient's needs. Aesthetic problems can be solved by selecting PEEK materials that are similar in color to the patient's abutment teeth, and highly polished PEEK brackets are less susceptible to staining and discoloration and have better long-term aesthetic results. Therefore, PEEK can be used as an alternative material to metal brackets for patients who are metal sensitive and cannot accept metal in the mouth. However, the design of PEEK brackets for removable dentures is particularly important because of the low retention of the retaining ring.[23] The retaining power of PEEK is not as good as that of metal retainers, but 0.5 mm below the recess is sufficient for clinical retention.[18] The PEEK retainer is not as good as the metal retainer, but it is sufficient for clinical retention at 0.5mm below the recess.

In a conventional removable partial denture, the artificial teeth are indirectly attached to the metal bracket through the abutment resin. The connection area between the structures in this design, such as the metal bracket and the abutment artificial tooth interface, can become a weak area of the entire restoration, leading to undesirable conditions such as fracture of the bracket and loss of the artificial teeth. The PEEK removable partial denture, which integrates a bracket, artificial tooth, and abutment resin, does not have such a bonding interface and therefore can avoid similar problems. At the same time, the traditional 3-layer structure of metal mesh, abutment resin, and artificial teeth requires a certain occlusal distance to ensure the thickness of the material and thus the strength of the restoration saddle base, so for patients with tight bites requiring removable partial denture restorations, the integral cut PEEK removable partial denture is expected to be an alternative to metal composite brackets.[24] PEEK is particularly suitable for allergic patients because its polymer has a very low solubility in water of $<0.3 \mu\text{g}/\text{mm}^3$. PEEK can be used as an alternative to dental Cr-Co alloys because it is lighter and does not cause corrosion.[25]

4. Modified materials of polyetheretherketone

In recent years, continuous research on polyetheretherketone modified materials to enhance their

performance has revealed that TiO₂/PEEK materials are white in color and can produce white retainers and artificial teeth that are closer in color to the patient's original teeth, resulting in higher patient satisfaction. The lower modulus of elasticity (4.1 GPa) of the PEEK material compared with that of CoCr alloy and titanium alloy (240 and 110 GPa, respectively) allows for a higher flexibility of the removable partial denture, which can be used to protect the abutment teeth and periodontal membrane in patients with distal and mid-dental free defects [26] The weight of the removable partial denture is reduced to a large extent.[4] The weight of the removable partial denture was largely reduced. Guo Fang et al.[7] The mechanical and mechanical properties of TiO₂/PEEK composites as removable partial denture scaffold materials were found to be superior to those of PEEK, which can better meet the clinical needs of oral prosthetics.

Bio-HPP (PEEK-based ceramic-reinforced high-performance polymeric material) is prepared by adding 20% ceramic particles with a diameter of less than 0.5um, which increases the hardness, elasticity and flexural strength of PEEK with high biocompatibility, good mechanical properties, high temperature resistance and chemical stability. Bio-HPP scaffolds are not only made to meet the general removable partial denture (1) high surface hardness; (2) excellent wear resistance; (3) very high fracture toughness; (4) low water absorption; (5) good polishability and polishability; (6) low flexure; (7) better positional stability; (8) no artifacts during CT imaging; (9) very light texture and minimal foreign body sensation; (10) no (10) no metal, no metal allergy; (11) all conventional sterilization can be used.[27] . Yao, Suxia et al.[27] found that the Bio-HPP CAD/CAM stent was superior to the cobalt-chromium alloy stent in terms of patient lightness. Due to the material characteristics of Bio-HPP itself, the color is white or cream, which is better than cobalt-chromium alloy in terms of aesthetics. However, Bio-HPP restorations are more flexible and have a significantly lower retention force than cobalt-chromium alloy (11.3 to 16.3 N). brackets[20] The clinical results of Bio-HPP brackets are better than those of cobalt-chromium brackets. Currently, Bio HPP retainers and brackets made by CAD/CAM have been used for patients with high aesthetic and comfort needs, taste sensitivity, and metal allergy. However, due to the lack of systematic evaluation, PEEK has not yet been able to replace metal retainers and brackets in removable partial dentures.[28] .

5. Processing of polyetheretherketone

PEEK processing methods include hot press casting, CNC cutting and 3D printing, and recent studies have shown no significant differences in the mechanical properties of PEEK oral prostheses processed by the three. 3D printing technology is now generally considered to be the ideal method for achieving complex forms of single-piece finished products and rapid manufacturing at low cost.[22] The most recent studies have shown no significant differences in the mechanical properties of PEEK prostheses produced by the three methods. Compared to other methods of denture processing, 3D printing technology has the advantages of simple preparation methods, short processing cycle, high material utilization, and the flexibility to prepare complex internal and external structures of the restoration, which allows the artificial teeth, retainers, connectors, and abutments to be prepared in one piece, and is more suitable for the clinical requirements of individualized removable partial denture preparation.[4] It is more suitable for the clinical requirements of individualized removable partial denture preparation. Lu Wei et al.[22] The experiments found that integrated two-color 3D printed PEEK oral prosthesis has certain clinical application feasibility, based on the original 3D printed PEEK denture on the color improvement, while achieving the production of removable denture brackets of two-color printing, has potential clinical application value, but there are still many problems to be solved, after observing the aesthetics of two-color printed PEEK denture and traditional dental resin still exists in a certain gap.

After observing that the aesthetic properties of two-color printed PEEK dentures still have certain gaps with traditional dental resins, it is considered that one is to continue to systematically carry out research on pigment blending of two-color PEEK materials, and the other is to use the PEEK surface bonding finishing resin method, which has significantly improved the aesthetic effect of the denture after baking plastic treatment due to the base color of PEEK material.

PEEK has good cutting properties and can be cut and molded by CAD/CAM technology. If PEEK is used in removable partial denture restorations, digital design and fabrication simplifies the fabrication process, reduces deformation and errors, and improves the fit of each component of the removable partial denture. The feasibility of CAD/CAM technology for the fabrication of new PEEK integrated removable partial denture was verified by Li Xinxin et al.[29] The results showed that PEEK can be further applied to clinical applications in the future.

6. Summary

PEEK and its modifications are promising materials for removable partial dentures. In the future, new PEEK composites continue to be developed to meet various applications in different branches of dentistry. However, the use of a new material in the field of dentistry still requires more basic and clinical research to provide theoretical support for the future development of PEEK materials.[30] Theoretical support for the future development of PEEK materials is needed.

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