Review Article

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Applications of PEEK in Prosthodontics: A Review

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ABSTRACT

Background: Prosthodontics has embraced several new restorative materials and techniques to perk up its ability to reinstate the oral health. Restorative materials [filling, denture and implant materials] are designed to reproduce the contour and purpose of natural teeth. Development in materials science and biomechanics has dramatically improved the way we look at the replacement of components of human teeth. Restorative biomaterials are the foundation for the replacement of hard tissue and it is unique because of the complexity of the oral cavity. One such material with an increasing use in prosthodontics is polyether-ether ketone (PEEK). In this report, the usage of PEEK in Prosthodontics is reviewed.

Keywords: Dentistry, PEEK, Prosthodontics.

INTRODUCTION

The organic polymer thermoplastic Polyetheretherketone, more commonly known as PEEK, is becoming increasingly popular. PEEK is a high-performance polymer that has been used in medicine for many years and has also proven successful in many areas of dentistry, as a direct result of CAD/CAM technology. PEEK is acronym for POLYETHERETHERKETONE, a member of the PAEK (poly aryl ether ketone) family. It is a highly ordered, flexible, resilient, shape-stable, biocompatible polymer machined to final shape, used for removable partial denture frameworks and implant components.[1] PEEK is characterized by excellent mechanical and chemical properties. It has long been used in medicine for the preparation of different kinds of implants. Artificial cranial plates, as a biomaterial in orthopedics components of finger and knee joints or intervertebral bodies (spine implants) are just a few examples of the versatile use of the material in the area of long-term implantation.[2-4]For several years, PEEK has also increasingly been applied in dentistry. Due to its combination of superior biocompatibility and ideal mechanical properties, the material is particularly suitable for dental restorations and it is ideal for CAD/CAM framework fabrication in prosthetic dentistry. PEEK offers a good combination of high tensile strength, stiffness, toughness, good wear resistance, low coefficient of friction, excellent chemical resistance, very low moisture absorption and a high melting point (about 343°C), resistance to fatigue. PEEK can be modified easily by incorporation of other materials, such as incorporation of carbon fibers, modulus of carbon-reinforced PEEK is comparable to those of cortical bone and dentin.[5-7] It has chemical stability to nearly all-organic and inorganic chemicals which makes it an interesting material for metal-free prosthodontics[8]

Morphology and Thermal Transitions of PEEK:

PEEK is a two phase semi crystalline polymer, consisting of an amorphous phase and a crystalline phase. The crystalline content of PEEK

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varies depending upon the thermal processing. The crystallization of PEEK is similar to that of polyethylene terepthalate(PET)[9]. The crystalline content varies from 30-35%, however there can be a slight border change depending on how it is being processed. The PEEK molecular chain favors a zig-zag conformation, with a bond angle of 125^0.

PEEK crystals consist of lamellae which under circumstances organize into large spherulites. The thickness of the two depends on the way it is being processed right from the melt. The structure of the lamellae as well as the spherulite can be studied under scanning electron microscope with suitable etching or under polarized microscope. The morphology under polarized light may be "a fine grained mosaic structure" of crystalline domains with varying birefringence[11].

The crystallization occurs at temperatures approaching t_g ~143^0 c. The crystalline content and microstructure for PEEK has been determined by x-ray diffraction. The x-ray measurement reveals that the density of the fully crystalline and amorphous phase of PEEK is around 1.400 and 1.25 g/cc, respectively[10]. The heat of fusion is also determined to be different for perfectly crystalline PEEK[9]. The identification of an absorption band specific to the crystalline phase can be used to determine the polymer crystallinity. Techniques by Cebe[12], and Chalmers[13] and refined version by Jones and Legras[14] can be used to determine the polymer cystallinity.

Physical Properties:

Tensile strength	97 mpa
Flexural strength	170 mpa
Flexural modulus	4.1 mpa
Notched impact strength	>5 kj/m^2

The material has a remarkable combination of strength, stiffness and toughness properties. It can injected moulded, extruded and machined and is highly flexible[15].

Chemical, Thermal and Radiation Resistance:

The structure of PEEK confines to its resistance against chemicals. The stable chemical structure of PEEK results in the delocalization of higher orbital electrons along the entire macromolecule making it highly unreactive and resistant to chemical, thermal and radiation degradation.PEEK has a water solubility of 0.5 w/w %. As mentioned above, it is not chemically damaged even after long term exposure to water at temperatures upto 260^0 c [16-18].

The thermal stability of PEEK has to be studied due to its application in high temperature industries and various processing conditions. There have been several studies which state that thermal degradation occurs in temperatures between the glass transition and melt transition[19-23]. Hay and Kemmish reported that the thermal degradation was difficult to measure at temperatures below 427^0 C[19]. Cole and Casella studied the thermal degradation using fourier transform infrared spectroscopy technique[22,23]. Based on studies conducted by Buggy.M, it is clear that thermal degradation is not a concern during clinical use as the temperature is around 37^0C [20, 21]

Radiation stability or resistance to radiation is another concern with regard to polymers, as they are susceptible to bond cleavage during exposure to radiation, and hence results in the release of free radicals [24]. Due to the distinctive aromatic structure, PEEK shows high resistance to radiation. It shows remarkable resistance towards gamma and electron beam radiation[25]. Even if free radicals are generated during exposure to radiation, they rapidly decay due to the reaction made by the mobility of the electrons along the molecular chain[26]. No significant changes in the mechanical behaviour of PEEK has been observed even on rapid sterilization [27]. Hence PEEK can be effectively sterilized using gamma radiations.

Mechanical properties of PEEK:

The mechanical properties of PEEK are highly influenced by strain rate and temperature. Furthermore it can also be influenced by molecular weight as well as the size and orientation of the crystalline regions. It has been stated that the mechanical properties of PEEK generally decrease with increase in the temperature up to 250^0c and also drop off is seen in the properties of PEEK. But since biomaterial application is only around 37^0c , the mechanical properties of the material remains unchanged[3].

Since studying the mechanical properties is more complex , previous authors have adopted a more simplified method that groups mechanical properties governing stiffness, strength and toughness. Stiffness included the initial elastic modulus as well as post yield softening or hardening of the material at large deformation. Strength property includes yield and ultimate stress characteristics. and toughness includes a broad range of fracture properties, under static, impact ad fatigue conditions [3]. The fatigue behavior of PEEK was first reviewed by Jones[28].

Biocompatbility and Biological Safety:

It is self evident that any biomaterial that is being used should be biocompatible, and this has been a topic of discussion starting in the late 1980s. Scientific evidences currently exists to support the biocompatibility of PEEK and PEEK composites . The biocompatibility testing of PEEK meets the criteria for the fda master files. The numerous studies were based on the systemic and intracutaneous toxicity and intramuscular transplantation all of which had shown no side effects. Gene toxicity test showed no chromosomal alteration and sensitization test showed no sensitization [3].

Applications of PEEK:

Unlike metal, PEEK is biocompatible and has a natural tooth-colored appearance, hence its widespread use in implants, provisional abutments, implant supported bars, or clamp materials in the field of removable dental prostheses and maxillary obturator prostheses[29-31]. PEEK also offers an alternative to orthodontic wires for reasons of improved aesthetics & allergies to metals[30]. Furthermore, PEEK can be easily shaped with dental burs, although, owing to its low translucency and grayish pigmentation, it still requires veneering[31]. Zoidis et al. described a case in which modified PEEK containing 20% ceramic fillers (BioHPP) was used, in combination with acrylic resin, the traditional denture base, as an alternative framework material for removable dental prostheses[32].

1. **RPD Frame work:** Dentures can be constructed by using PEEK computer-aided design and computer-aided manufacture systems[3]. The advantages to the patient when using a PEEK partial denture framework are many. It's strong and lightweight for improved patient comfort; digital design matches the patient's individual anatomy; the metal-free denture framework is a tasteneutral (no metal taste); has no thermal or electrical conductivity; is x-ray and scanner friendly; and is non-allergenic. PEEK frameworks are also shock absorbent during chewing; and have a high resistance to abrasion and decay. A modified PEEK material containing 20% ceramic fillers is a high performance polymer which presents high biocompatibility, good mechanical properties, high temperature resistance, and chemical stability. Due to a 4 GPa modulus of elasticity, it is as elastic as bone and can reduce stresses transferred to the abutment teeth.

2. **PEEK Crowns & Bridges:** Materials used for fixed partial dentures (FPDs) have evolved over the years. Metals such as Ni and Cr are routinely used for making the framework for fixed prosthesis. Nowadays, metal-free restorations are becoming more popular in dentistry. Ceramic materials ideally meet the esthetic requirements, but they may also have a few material or technical disadvantages in some cases. Unlike metal, PEEK is biocompatible and has a natural tooth-colored appearance, Mechanical properties of PEEK makes it suitable for permanent metal free crowns and bridges. It also allows diagnostic treatment without substructure removal. It has stiffness compared to metal which is aimed at improving comfort with excellent preservation of antagonist natural tooth. A variety of procedures have been suggested to condition the surface of PEEK in order to facilitate its bonding with resin composite crowns. Even though air abrasion with and without silica coating creates a more wettable surface[31], etching with sulphuric acid creates a rough and chemically altered surface which enables it to bond more effectively with hydrophobic resin composites[33]. As the mechanical properties of PEEK are similar to those of dentin and enamel, PEEK could have an advantage over alloy and ceramic restorations.

PEEK as an Implant material: Since decades Titanium and its alloys have been the universal choice for implant material. Titanium's strength, low weight and biological inertness made it the prime candidate for making "fit and forget" implants. Titanium can undergo corrosion due to breaking down of stable oxide layer. Galvanic coupling of titanium to other restorative materials may also generate corrosion[34]. Although the placement of titanium (Ti) dental implants can be associated with complications such as hypersensitivity to Ti in some patients. There are studies which show Ti as an allergen, but the resources to diagnose Ti sensitivity are very limited[35]. Unmodified PEEK, is considered as a bioinert material, still there has been no conclusive data of osseoconductive effects of PEEK in vivo and in vitro. Hence, in its unmodified form, the long term survival rate of PEEK implants is debatable. In order to improve the bioactivity of PEEK, certain surface modification have been done to modify or coat the surface of PEEK implants at a nanometre level[36]. For eg. Nano-structured PEEK surfaces produced by etching with sulfuric acid (sulfonation) and rinsing with distilled water have been observed to induce an accelerated osseointegration compared to the unmodified PEEK in vitro and in vivo[37]. Surface modification methods include, direct surface modification and deposition techniques.

Direct surface modification methods are techniques that changed the surface properties of the material without depositing any layer of new material on the surface.

It consist of the following techniques; (i) wet chemical treatment, (ii) plasma surface treatment, (iii) laser surface modification, (iv) accelerated neutral atom beam surface treatment, (v) ultraviolet or ozone surface treatment.

Deposition techniques are techniques in which the PEEK implant is coated with a material and the trend of progress is described based on the coated material. It consist of the following techniques; (i) plasma spray, (ii) vacuum plasma spray, (iii) radio frequency magnetron sputtering, (iv) arch iron plating, (v) electron beam deposition, (vi) chemical deposition.

It has been demonstrated that PEEK abutments can withstand intra oral masticatory forces similar to that of titanium abutments. PEEK abutments provide a cost effective versatile solution allowing chair side modification in the dental surgery at the time of implant placement[38]. Furthermore PEEK's proven soft tissue behaviour supports the good recovery of gingival tissue. Further research and clinical trials are required to explore this material and possible modifications for further dental applications.

CONCLUSION

The field of dentistry is constantly evolving and changing to best suit patient needs. Advancements in dental materials by utilizing technology to make more comfortable, durable, efficient and natural-looking for the patient as possible offer better solutions for traditional oral health problems than ever before. The use of PEEK material has been increasing in volume and applications as it offers an alternative to traditional dental materials. Because of its mechanical and physical properties being similar to bone and dentin, PEEK can be used for a number of applications including dental implants. Increasing the bioactivity of PEEK dental implants without affecting their mechanical properties is a major challenge. PEEK is also an attractive material for producing CAD-CAM fixed and removable prosthesis owing to its superior mechanical properties compared to materials such as acrylic.

Future research and ever evolving technology results in improvement of materials and techniques used in dentistry particularly in prosthodontics. Due to their properties and advantages inventive techniques must be regarded as potential alternatives to traditional materials.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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