Review Article

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Polyetheretherketone (PEEK) in Dentistry

VEENA B BENAKATTI[1], JAYASHREE A SAJJANAR[2], ADITYA ACHARYA[3]

ABSTRACT

There has been a constant research in identifying ideal restorative materials to replace lost dentofacial structures. Material such as wood, shell, ivory, rubbers to metals and plastics have been tried in the past. Advancements in dental materials have given dentistry more promising materials, yet each material remains short of being the ideal one. Oral conditions demand a material with good mechanical and biologic properties in addition to aesthetics. At present Polyetheretherketone (PEEK) is one of the viable materials among scientifically approved and safe materials in restoring the lost orofacial tissues. Due to its excellent properties peek has several applications in field of dentistry like implants, removable and fixed partial dentures, and orthodontic wires.

Keywords: Aesthetic dentistry, Implant, Surface treatment

INTRODUCTION

In view of aesthetic concerns, metal free restorations are gaining popularity in current dental therapies. PEEK is one among the metal free restorations that has many potential uses in dentistry. Due to its excellent properties PEEK is gaining importance in oral implantology and prosthodontics [1]. Titanium (Ti) and its alloys have been used as dental implants since its introduction by Brånemark. Ti materials have certain clinical issues, such as occasional metal hypersensitivity and allergies, surface degradation and contamination related to peri-implantitis, high modulus of elasticity and the metallic color which is less acceptable in aesthetic regions. PEEK-based materials can overcome these problems and can be a viable substitute to titanium [2]. Due to its excellent mechanical and aesthetic properties PEEK can also be used as framework for removable and fixed dental prosthesis, orthodontic wires [3]. This paper summarises the properties and application of PEEK for dental purposes.

History of PEEK

PEEK is a polyaromatic semi crystalline thermoplastic polymer originally introduced by victrex PLC then ICI (imperial chemical industries) in early 1980s for engineering applications. It was first commercialised for industrial applications in manufacture of aircraft, turbine blades, piston parts, cable insulation, bearings and compressor plate valves [1]. Later in 1998 it was proposed for biomedical application by Invibio Ltd (Thornton-Cleveleys, UK). In the same year Victrex PEEK business (Imperial Chemical Industry, London UK) launched PEEK-OPTIMA for long-term implantable applications [4].

Structure and Properties of PEEK

PEEK is a colorless organic thermoplastic polymer a member of PAEK family. It is a homopolymer having a single monomer. It is a semicrystalline thermoplastic with exceptional chemical and mechanical properties that are retained even at higher temperatures. Length, chemical composition, structure (branching of polymer) of PEEK renders it stable at high temperatures making processing of peek implant components easy [5]. PEEK shows resistance to deterioration during various sterilisation procedures; hence it can be sterilised with heat sterilisation methods without affecting its properties [6]. Its chemical structure makes it highly resistant to chemical and radiation damage, compatible with reinforcing agents such as glass and carbon fibers, greater strength than metals. These properties make it highly suitable of industrial applications [5].

PEEK is widely used not only in engineering applications but also in medical applications because of its excellent thermal properties, superior wear resistance, great processability, inertness, corrosion resistance, high strength and modulus of elasticity [5]. PEEK has elastic modulus that in close to human bone suggesting homogeneous stress distribution to surrounding tissues. Radiographic radiolucency and low density (1.32 g/cm^3) makes it suitable for medical applications [1,7,8]. Radio pacifiers like barium sulfate can be added to improve visualisation and contrast in medical imaging [5].

PEEK is an inert material highly compatible with surrounding tissues and do not exhibit any toxic or mutagenic effects. Therefore, it can be an ideal substitute for patients allergic to titanium and other metals. PEEK does not have metallic color; it is beige with a touch of grey and has more aesthetic appearance [9].

PEEK Processing and Manufacturing

PEEK implant components are manufactured using injection molding, extrusion and compression molding techniques [5]. As an alternate to these techniques Rapid Prototyping and CAD CAM milling produces quick, highly precise prostheses without compromising quality of material [10].

Applications of PEEK in Dentistry

Owing to its excellent properties, PEEK succeeded as a biomaterial in medicine; soon it found its application in dentistry. Different surface modifications have allowed PEEK to bond with various luting agents. Tensile properties of PEEK are comparable to bone, enamel and dentin, which makes it a suitable dental restorative material. With good biocompatibility and afore mentioned properties PEEK is successfully used in dentistry as implants, framework for removable and fixed prosthesis [3].

a. As Implant Material

Dental implants make one of the most viable replacements for missing tooth. Titanium has been the material of choice for dental implants since its introduction by Branemark. However, titanium lacks certain important properties. There are reported cases of hypersensitivity to material. The difference in elastic moduli of Titanium and surrounding bone, leads to stress shielding and bone resorption. Major benefit of PEEK as an implant material is its Youngs modulus which is close to human bone, thus it can generate favorable stress and deformations minimising stress shielding effect and bone resorption. Unfilled PEEK exhibits an elastic moduli of 3-4Gpa. The addition of reinforcing agents like carbon fibers increases elastic modulus of PEEK up to 18Gpa which matches elastic moduli of bone (14Gpa). Titanium provokes a dark shimmer of periimplant tissue in cases with thin biotype and mucosal recession which produces unaesthetic appearance in patients, especially with high lip line. PEEK can be alternative to titanium in such cases [2,11]. The long-term presence of metals results in tissue reactions and osteolysis [12].

Corrosion-resistance, bioactivity and biocompatibility, non-toxicity, all are shown by Bioactive ceramics. However, the demands for load-bearing applications cannot be fulfilled because of the mechanical properties of ceramics, like their ductility, low fracture toughness, brittleness and high elastic modulus [12]. Elastic modulus of zirconia is 210 gpa which is about 14 times greater than compact bone (14gpa). These stiff implants do not adequately strain the bone, resulting in disuse atrophy and bone resorption [9]. PEEK makes an alternative to ceramics in terms of mechanical properties.

Although unmodified PEEK is considered a bioinert material, there is no conclusive evidence of osseoconductive effects; hence unmodified peek implants survival is questionable. Inadequate osseoconductivity and bioactivity of the dental implant may lead to severe implantitis and implant failure [13].

These are some of the current strategies to improve the bioactivity of PEEK [12].

- Physical treatment
- Chemical treatment
- Surface coating
- Composite preparation

To improve bioactivity of PEEK several surface modifications have been tried, physical treatment like plasma modifications (such as nitrogen and oxygen plasma, ammonia/argon plasma, oxygen plasma, methane and oxygen plasma, ammonia plasma, oxygen and argon plasma, and hydrogen/argon plasma) and Accelerated neutral atom beam (ANAB). Plasma modification resulted into increase adhesion, proliferation and osteogenic differentiation [1].

Chemical treatment like wet chemistry and sulfonation, surface coating by titanium, gold, titanium dioxide, diamond-like carbon, tert-butoxides, and hydroxyapatite have been considered. The hydroxyapatite is the most widely used material due to its biocompatibility, bioactivity, and osteoconductivity in vivo. Surface coatings can be applied using the following techniques: aerosol deposition, vacuum plasma spraying, arc ion plating, plasma immersion ion implantation and deposition, physical vapor deposition, cold spray technique, electron beam deposition, ionic plasma deposition, radio-frequency magnetron sputtering, and spin coating [1]. Devine et al compared bioactivity of titanium coated and uncoated implants and concluded that Ti coating of Carbon fiber PEEK screws significantly improve bone apposition and removal torque compared with uncoated Carbon fiber PEEK screws. Author also compared the titanium coating by physical vapor deposition and vaccum plasma spraying and concluded that VPS-coated screws had a screw removal torque which was statistically greater than uncoated and PVD-coated screws [14]. Thin layer of nanoscale calcium hydroxyapatite has been tried as a coating on PEEK by a process called spin coating. In this process apatite is dissolved in organic solvents and dropped onto implant surface rotating at high speeds. These spin coated implants showed higher bone implant contact in comparison to unmodified PEEK. Alternatively plasma gas etching is another procedure to produce nanoscale surface modifications for PEEK in which low pressure gases are used to introduce nanolevel surface roughness and functional groups on PEEK. This induces more hydrophilicity for better material tissue interaction. These gas plasma modified implants showed improved proliferation and differentiation of mesenchymal cells on implant surface. Various other methods of surface deposition like electron beam deposition has been tried to enhance hydrophilicity and cellular proliferation [3].

Composite preparation, bioactivity of PEEK can be improved by impregnating it with bioactive materials. Depending on the size of these materials, PEEK composites are classified as conventional PEEK and nanosized (<100 nm) PEEK composites. One conventional PEEK composite, that is hydroxyapatite, has good biocompatibility, bioactivity, osteoconduction, and can be used as a filler material to prepare PEEK composites. The increase in the amount of HA content improves tensile modulus and micro hardness, but decreases tensile strength and strain to fracture [1].

Bioactive inorganic particles have been inserted to PEEK with melt blending and compression molding techniques in order to enhance its bioactivity. These bioactive nanocomposites also have improved mechanical properties. Hydroxyfluoroapatite has been suggested to impart antimicrobial properties against streptococcus mutans and also enhance osseointegration. Bioactive PEEK nanocomposites can also be used as indirect intracoronal and extracoronal restorations, as they have advantage of antibacterial properties in addition to better mechanical properties [3].

PEEK can be used as implant abutments as they exhibit comparable bone resorption and soft tissue inflammation to titanium abutments. In addition closely matching elastic modulus of bone and PEEK reduces stress shielding effect and encourage bone remodeling. Thus PEEK can be viable alternative to titanium abutments [3]. However, because of its lower fracture resistance PEEK is not used as a definitive abutment material [1].

b. In Removable Prosthesis and its Components

Owing to its light weight, superior biologic, aesthetic and mechanical properties PEEK can be used to construct clasps and dentures by CAD CAM systems. Another application would be to make removable obturators [1,3]. Biocompatibility, resistance to cracking, flexural bone modulus, machinability and ease of polishing of PEEKOPTIMA (reinforced poly-ether-etherketone) allows material to be used in the palatal section of maxillary obturator prostheses. Costa-Palau S et al., fabricated maxillary obturator prosthesis using PEEK and found that the use of PEEK simplified the fabrication of the antral section of the obturator and resulted in significantly lighter obturator prosthesis. Retention, aesthetics and patient comfort were greatly improved. Constructing obturator prosthesis with PEEK-OPTIMA is a good alternative to conventional materials and methods for patients with large oral-nasal defects [15]. In a partial denture framework made of PEEK, patient comfort is improved because of its strength and lightweight, digital design customises individual anatomy, absence of metal taste), no thermal and electrical conductivity, scanner and x-ray friendly, non-allergenic. PEEK frameworks are shock absorbent during mastication, have an excellent resistance to decay and abrasion. Although metals exhibit good strength but resiliency and patient comfort are also of great concern [16].

Despite good fracture resistance, PEEK is weak mechanically in homogenic form. Tannous F et al., in vitro research showed that PEEK clasps have lower resistance forces in comparison to cobaltchrome [17]. Hence lead to the development of modified PEEK containing 20% ceramic fillers known as BioHPP (Bredent GmbH Senden, Germany). Possibility of corrections, good stability, optimal polish ability and aesthetics of BioHPP produce high-quality prosthesis. BioHPP with a great potential as framework material, makes good alternative to Cr-Co frameworks in patients with high aesthetic requirements [18].

c. As a Framework in Fixed Prosthesis

Since PEEK is opaque it should be veneered with composites to attain aesthetics. The colour of PEEK which is grey in unfilled material can be ad-justed by incorporating appropriate pigments. Since PEEK is chemically inert different methods have been tried to attain good bond strength with veneering materials. These surface treatments include sandblasting, rocatec procedure, surface etching with sulfuric acid and piranha solution [7,19]. Recent method of surface modification is with plasma, which removes organic residues, microetch surface and allows cross linking and surface activation [7]. Surface modification of PEEK have been investigated for bonding with different luting agents, multifunctional methacrylates containing resin varnish on air-abraded PEEK surfaces produces a promising and durable bond to PEEK, hence PEEK can be recommended for clinical use [20,21].

Considering good abrasion resistance, mechanical attributes and different techniques of bonding to composites and teeth, a PEEK fixed partial denture would be expected to have a satisfactory survival rate [3,22].

CONCLUSION

Due to excellent physical, mechanical, aesthetic properties and biocompatibility, PEEK can be used in many instances in dentistry such as implants, fixed and removable prosthesis. The major challenge for PEEK as implant material is to enhance the bioactivity without affecting its properties. Further investigations are still required to test bioactivity of PEEK through different materials and techniques. Bone replacement material for nasal, maxillary and mandibular reconstructions, osteosynthesis plates, skull implants and dental implants will be possible applications of PEEK. CAD CAM and rapid prototyping has allowed manufacturing of customised prosthesis. Reinforcement with carbon fibers has improved the mechanical properties of PEEK; hence CFR-PEEK has become more promising alternative to metallic materials.

PEEK polymers are inherently strong, inert, and biocompatible, neither the bulk material nor its particulates elicit adverse biological response than any other available biomaterials that have been in clinical use for many years.

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PARTICULARS OF CONTRIBUTORS:

1. Lecturer, Department of Prosthodontics, KAHERS, Klevkids, Belagavi, Karnataka, India.
2. Senior Lecturer, Department of Prosthodontics, Swargiya Dadasaheb Kalmegh Smruti Dental College and Hospital, Nagpur, Maharashtra, India.
3. Lecturer, Department of Prosthodontics, KAHERS, Klevkids, Belagavi, Karnataka, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Veena B Benakatti,
Lecturer, Department of Prosthodontics, KLEVK Institute of Dental Sciences, Nehru Nagar, Belagavi, Karnataka, India.
E-mail: veenak20021@rediffmail.com

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