POLY ETHER ETHER KETONE IN PROSTHODONTICS

ABSTRACT

With the introduction of computer aided designing and manufacturing techniques in dentistry, it has become possible to fabricate restorations, frameworks and appliances using modern biocompatible materials including alloys, ceramics and high-performance polymers. Poly Ether Ether Ketone (PEEK) is a colorless organic thermoplastic polymer in the Poly Aryl Ether Ketone (PAEK) family, with excellent mechanical and chemical resistance properties that are retained to high temperatures. It is highly resistant to thermal degradation as well as attack by both organic and aqueous environments. PEEK melts at a relatively high temperature (343°C) compared to most other thermoplastics. PEEK has the potential to be used in load-bearing dental applications as abutments, fixed prosthetic frameworks, removable partial denture frameworks including precision attachments, implants, maxillofacial prosthesis etc. The properties and various applications of PEEK as a viable alternative to conventional materials used in prosthodontics are thus described here.

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INTRODUCTION

Poly Ether Ether Ketone (PEEK) is an aromatic, linear, semicrystalline polymer synthesized from aromatic dihalides and biphenolate salts by nucleophilic substitution. It was initially created by a group of English researchers in 1978. In the 1980s, PEEK was popularized for modern applications, for example, airplanes and turbine edges. By the late 1990s, PEEK turned into a promising polymeric alternative to metal implant components, particularly in orthopedic and for traumatic applications. In the course of recent years, PEEK and its composites have furthermore garnered much enthusiasm from dental technologists and dentists. Besides aesthetics, the fundamental main thrust is given by PEEK's incredible biomechanical properties.[1]

PROPERTIES

The elasticity of the material, which lies within the range of bone, makes it able to compensate for the torsion of bone, in particular for larger implant work. The aesthetic white shade supports its use in the field of prosthetics. Its insolubility in water makes it a biocompatible material, which is ideal for patients with allergies. PEEK has a great potential as framework material, both for fixed and removable dental prostheses. They are lighter and easier to work with in dental laboratories compared to titanium or ceramics.

PEEK is resistant to mechanical forces and thermal and oxidative attacks, as well as high temperature,[2] which made PEEK an attractive biomaterial for medical use, especially due to its ability to be sterilized by radiation and heat without structural damage.[3,4] This is a partially crystalline, thermoplastic high temperature-resistant high-performance plastic with a melting temperature of approximately 334°C. PEEK is therefore suited for processing in extrusion and injection moulding procedures, but can also be used to manufacture tense rotating parts and milling parts. The material is highly stable and can bear pressures of up to 3.6 GPa. Despite having desirable mechanical properties for dental prostheses, PEEK does not meet the aesthetic requirements. Thereby the opacity and color of the material require the application of a veneering material.[6] To obtain adhesion to veneering resins and cements, the PEEK surface requires treatment since it has low surface energy.

Table 1. Properties of PEEK

Density	1320kg/m3
Young's modulus	3.6 GPa
Tensile strength	90-100 MPa
Elongation	50%
Notch test	55 kJ/m2
Glass temperature	143 °C
Melting point	~343 °C
Thermal conductivity	0.25 W/m.K
Water absorption, 24hours	0.1%
Water solubility	Insoluble
Flexural Modulus	4 GPa
Flexural Strength	170 MPa

PEEK IN PROSTHODONTICS

PEEK is quite new material in prosthodontics. Comparing to the metals used in dentistry, PEEK is more aesthetic, stable, biocompatible, lighter and has reduced degree of discoloration.[13] However, due to its grayish-brown color PEEK is not suitable for monolithic aesthetic restorations of anterior teeth.[7]

Prosthodontic applications include veneers, dental implants, abutments, fixed prosthetic frameworks, removable partial denture frameworks, precision attachments, secondary and telescope restorations, attachment restorations, screw-retained and implant-supported superstructures, palatal section of obturator prosthesis etc.

PEEK AS REMOVABLE PROSTHESIS MATERIAL

The esthetically unacceptable display of metal clasps, the increased weight of the prosthesis, the potential for metallic taste, and allergic reactions to metals led to the introduction of a number of thermoplastic materials in clinical practice such as nylon and acetal resins. The major disadvantage of nylon is the inability for a reline procedure and the lack of occlusal rests as well as rigid frameworks that could lead to occlusal instability. On the other hand, acetal resins lacks natural translucency and vitality.[8] PEEK has been successfully used as an alternative material over the last years. 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.[9]

Dentures can be constructed by using PEEK computer-aided design and computer-aided manufacture systems.[3] Tan-nous et al.[10] has suggested that denture clasps made of PEEK have lower retentive forces compared to cobalt-chromium (Co-Cr) clasps. However, owing to the superior mechanical and biological properties of PEEK, it will not be surprising if dentures constructed from the polymer are routinely constructed in near future.

PEEK AS CROWNS

A variety of procedures have been suggested for conditioning the surface of PEEK in order to facilitate its bonding with resin composite crowns. Even though air abrasion with and without silica coating can result a more wettable surface,[7] etching with sulphuric acid creates a rough and chemically altered surface which enables it to bond more effectively with hydrophobic resin composites.[11] Because the mechanical properties of PEEK are similar to those of dentin and enamel, PEEK could have an advantage over alloy and ceramic restorations.

PEEK CAD-CAM MILLED FIXED PROSTHESIS

Using CAD-CAM to manufacture restorations makes it possible to produce dental prostheses chairside.[12] PEEK can be used an alternative to PMMA for CAD-CAM restorations. The fracture resistance of the CAD-CAM milled PEEK fixed dentures is much higher than those of lithium disilicate glass-ceramic, alumina and zirconia.[13] PEEK has excellent abrasive properties. Considering good abrasion resistance, mechanical properties and adequate bonding to composites and teeth, a PEEK fixed partial denture would be expected to have a satisfactory survival rate.

PEEK AS AN IMPLANT MATERIAL

Titanium (Ti) and its alloys have been used as dental implants since Brånemark introduced them at the end of the 1960s. Titanium materials possess good physicochemical characteristics, mechanical properties, biocompatibility, and high resistance to fatigue stress and corrosion. However, Ti materials have an elastic modulus significantly higher than that of bone, that may result in inadequate stress-shielding, bone resorption, and implant fracture. Titanium has also been demonstrated to have occasional metal hypersensitivity and allergies, surface degradation and contamination related to peri-implantitis, and scattered radiation. The metallic appearance of titanium materials may also be problematic, as highly aesthetic restorations are becoming important. Polymeric compounds, such as polyetheretherketone (PEEK), have been developed as additional substitutes. It can be applied to materials as a superstructure, implant abutment, or implant body.[14]

PEEK Reinforcement

The elastic modulus of PEEK is very low compared to those of cortical bone, titanium, and ceramic materials. Dental implant materials, those are used for abutments and superstructures requires higher elastic modulus that PEEK possess. Various reinforced PEEK composites developed include carbon fiber-reinforced PEEK (CFR-PEEK) and glass fiber-reinforced PEEK (GFR-PEEK). The elastic moduli of the material properties, including reinforced PEEK materials, are shown in Table 2.

SURFACE MODIFICATION

PEEK is chemically bioinert. Literature reports various surface modifications for improving bioactivity of PEEK which include: (i) plasma treatment, (ii) chemical surface modification and (iii) surface coating.

Plasma describes an ionized gas mixture in which highly reactive radicals are formed. These can cause different reactions with the substrate surface. There are different methods for plasma generation, which differ in energy supply and pressure conditions. Treating PEEK with plasma has been demonstrated with various modifications for obtaining significant changes in the surface properties. The hydrophilic character of the material is changed by the addition of polar groups resulting in a much better wettability and an increase in surface energy.[1]

Chemical surface modification of PEEK is extremely challenging due to the very high physical and chemical stability of the high performance polymer.

The deposition of a thin layer of a bioactive material applied as a surface coating on implants presents a further modification process to improve the bioactivity of surfaces. Often this modification is combined with a previous plasma or chemical treatment to augment the bonding properties. Titanium and hydroxyapatite coatings are significantly useful for enhancing osseointegration. Various techniques are available for the application of bioactive coat-

Table 2. Elastic moduli of various materials. (courtesy: Dent. J. 2017, 5, 35)

Material	Elastic Modulus (GPa)	References
Titanium	110	Lee, 2012
Cobalt-Chromium	180–210	Wiesli, 2015
Zirconia	210	Lee, 2012
Porcelain	68.9	Lewinstein, 1995
PMMA	3–5	Vallittu, 1998; Zafar, 2014
PEEK	3–4	Sandler, 2002
CFR-PEEK	18	Sandler, 2002
Continuous CFR-PEEK	150	Schwitalla, 2015
GFR-PEEK	12	Lee, 2012
Cortical bone	14	Martin, 1989; Rho, 1993
Cancellous bone	1.34	Borchers and Reichart, 1983
Enamel	40–83	Staines, 1981; Rees, 1993; Cavalli, 2004
Dentin	15–30	Rees, 1993; Chun, 2014

ings on PEEK: (i) spray-coating, (ii) dip-coating,(iii) spin-coating, (iv) aerosol-coating and (v) physical vapor deposition.[1]

Surface modifications of PEEK has been summarized in table 3.

LIMITATIONS

PEEK reports to stimulate less osteoblast differentiation comparing with titanium. Its bioinertness results in not possessing any inherent osseoconductive properties. High temperatures involved in plasma-spraying have shown to deteriorate PEEK. Owing to their limited bond strength, thick calcium phosphate coatings on PEEK can delaminate when compared to coated titanium implants.

CONCLUSION

PEEK with its added benefits of greater biocompatability, high strength and some exceptional material properties, has the potential for shifting paradigms in device design and performance. Its superior biocompatability and ideal mechanical properties makes it attractive material for dental restorations and it is ideal for CAD/CAM framework fabrication in prosthetic dentistry. The unique combination of X-ray and CT translucency and MRI compatibility, adjustable mechanical performance, chemical resistance, sterilisation options and the ability to be easily thermally processed makes PEEK an interesting alternative material to titanium or other implantable materials. However, more clinical research is necessary to find out the situation, because most of the studies have been carried out in vitro.

Table 3. Surface modifications of PEEK (courtesy: Dent. J. 2017, 5, 35)

Surface Modifications	Procedures	Material	References
COATING	Plasma spraying	Hydroxyapatite (HA), titanium (Ti)	Rust-Dawicki, 1995; Suska, 2014; Ha, 1994
	Spin coating	Nanosized HA crystals containing surfactans, organic solvent, an aqueous solution of Ca(NO3)2 and H3PO4	Barkarmo, 2012; Johansson, 2014
	Electron beam evaporation (EBE)	Ti, Silicate	Han, 2010, Wen, 2016
	Plasma immersion ion implantation (PIII)	Titanium dioxide (TiO2), calcium (Ca), water (H2O); Argon (Ar)	Wang, 2014, Lu, 2014, Lu, 2016, Chen, 2017
SURFACE TOPOGRAPHICAL MODIFICATIONS	Acid etching	Sulfuric acid	Zhao, 2013
	Sandblasting	TiO2, alumina (Al2O3)	Suska, 2014; Xu, 2015
CHEMICAL MODIFICATIONS	Sulphonation	Sulfonate groups (–SO3–)	Yee, 2013
	Amination	Amine functions	Henneuse-Boxus, 1998
	Nitration	Nitrate functions	Conceição, 2009
INCORPORATING WITH BIOACTIVE PROPERTIES	Bioactive inorganic materials	Nano-TiO2 (n-TiO2), nano-fluorohydroxyapatite (n-FHA)	Wu, 2012, Wang, 2014
IMPROVING HYDROPHYLICITY	UV irradiation	UV-A light, UV-C light	Qahtani, 2015
	Plasma gas treatment	Oxygen plasma	Waser-Althaus, 2014; Xu, 2015; Poulsson, 2014

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