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Review Article

POLY-ETHER-ETHER-KETONE (PEEK): A REVIEW

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ABSTRACT

Materials used for the fabrication of dental prosthesis should meet certain requirements such as stability in the oral environment, biocompatibility with the surrounding soft tissues of the oral cavity etc. Also, they should be esthetically pleasing. There are various materials used in the field of dentistry, each of which has its own merits and demerits. Polyether ether ketone (PEEK) has been used in the field of orthopedics for a long time now. It was introduced in the field of dentistry recently and this review was carried out to understand the material in depth.

INTRODUCTION

Polymer such as PolyMethylMethAcrylate (PMMA) has been widely used for the fabrication of complete denture prosthesis, transitional dentures, and interim dentures. It has also been used for the fabrication of denture bases, custom trays and provisional restorations. Some of the materials are being used in Maxillofacial Prosthodontics exclusively to replace the missing body parts. This polymer is easy to use and manipulate and is readily available but the main drawback of resin or polymer is the exothermic reaction that takes place during the polymerization which is harmful to the soft tissues. Another disadvantage is the leaching out of monomer for a long period of time which can cause irritation to the surrounding environment. For science to evolve there is always a need for research and development to take place so that the older materials are replaced by the improved ones which have better properties in terms of biocompatibility and strength. There are newer materials in the field of dentistry to overcome these disadvantages which are being researched and one of them is PolyEtherEtherKetone (PEEK).

PolyEtherEtherKetone (PEEK) is a colourless organic thermoplastic polymer in the PolyArylEtherKetone (PAEK) family. It was originally introduced by Victrex PLC and later by Imperial Chemical Industries (ICI) in the early 1980s.

DISCUSSION

Structural properties

PEEK is the dominant member of the PAEK polymer family. At temperatures between 390 and 420 ^{0} C PEEK can be processed either by injection molding, extrusion or compression molding. Whereas, at room and body temperature, PEEK is in its ‘glassy’ state, as its glass transition temperature is approximately 143^{0} C. The crystalline melt transition temperature is approximately 343 ^{0} C. After polymerization, at room temperature, PEEK is chemically inert and insoluble in all conventional solvents, except in 98% sulfuric acid.[1]

Chemical and thermal stability

Chemical stability: The structure of PEEK shows excellent chemical resistance. The aryl rings are interconnected by ketone and ether groups located at opposite ends of the ring (referred to in chemistry as the ‘para’ position). The resonance stabilized chemical structure of PEEK results in delocalization of higher orbital electrons along the entire macromolecule, making it extremely unreactive and inherently resistant to chemical, thermal, and post-irradiation degradation. PEEK cannot be damaged by exposure to any solvent except concentrated sulfuric acid. The inertness of PEEK’s chemical structure explains its biocompatibility. Water solubility of

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PEEK is 0.5 w/w%, but it is not chemically damaged by long-term exposure to water, even at high temperatures (up to 260 ^{0}C) [3-5]. Studies done by Dawson and Kwarteng have shown no significant changes in flexural mechanical properties of PEEK composites after exposure to high-temperature saline environments [2,7].

Thermal stability: Hay, Buggy and Cole in their studies have shown that thermal degradation occurs in PEEK at temperatures between its glass transition temperature and melt transition temperature, but temperatures exceeding the processing temperature of PEEK are needed to produce volatile degradation products [8-12]. Hay and Kemmish [8] reported that thermal degradation, accompanied by the generation of volatiles, was difficult to measure below 427 ^{0}C. Buggy and Carew [9,10] did a study on the degradation of flexural properties and crystallinity oriented in PEEK composite laminates (APC-2) between 120 ^{0}C and 310 ^{0}C for up to 76 weeks. They observed at 120 ^{0}C, which is below the glass transition temperature for PEEK, there were negligible changes in the static and fatigue properties [36]. At 250 ^{0}C, mechanical degradation was detected after 16 weeks of thermal aging, whereas aging at 310 ^{0}C showed 'rapid' degradation [36]. Based on these studies, we can state that thermal degradation is not a concern during clinical use of PEEK biomaterials around 37º C.

Biocompatibility of PEEK

Toxicity and cytotoxicity studies

Williams and colleagues [1] reported the first animal studies of PEEK in the literature. Neat PEEK and CFR samples produced by ICI (including 450G resin) were subcutaneously implanted in rabbits for 6 months and submuscularly implanted in rats for 30 weeks. They observed "minimal response'' in both animal models. Wenz *et al*. [13] conducted the first cell culture cytotoxicity experiments for PEEK using mouse fibroblasts. They used 30% polyacrylonitrile carbon-fiber reinforced (PAN CFR) composite PEEK material (LNP Corporation). After 96 h of exposure to PEEK, the cell culture was healthy. They concluded that the PEEK composite exhibited ''excellent'' in vitro biocompatibility in this cell culture model. Katzer *et al*. [15] performed cytotoxity testing on 381G PEEK resin. They selected the hypoxanthine-guanine-phosphoribosyl- transferase test for cytotoxicity. The results confirmed that PEEK was not cytotoxic.

Immunogenesis

Petillo and coworkers [14] studied the inflammatory response of an unspecified grade of PEEK using cage implant system in rats. They studied early cellular response to implantation of a variety of polymeric biomaterials after 4, 7, and 14 days. The authors found evidence that polymer composition influenced the cellular response following implantation.

Genotoxicity

Katzer *et al*. [15] performed Genotoxicity testing in which the Ames test was selected to evaluate PEEK 381G resin for mutagenicity. These tests confirmed that PEEK was not mutagenic.

Bioactivity of PEEK

Bioactive PEEK composites

Bioactive PEEK composites are PEEK compounded with calcium phosphate biomaterials, such as beta-tricalcium phosphate (b-TCP) and hydroxyapetite (HA). The initial research on PEEK-HA composites studied characterizing the composition and thermal characteristics of the polymer mixture [16]. These studies confirmed that HA did not interfere with the crystallization or melting processes of PEEK-HA powder mixtures. Since then the Injection molding technique has been a common method reported to produce PEEK-HA composites with HA fractions of up to 40% by weight. Loading PEEK with HA particles shows a significant increase in elastic modulus [18,19]. Whereas, with carbon and glass fiber additives, it does not show a strong mechanical affinity to the PEEK matrix. They concluded that pure PEEK was non-toxic and that cell proliferation was progressively inhibited when b-TCP was present. This suggests that PEEK possesses good biological interaction.

Bioactive and textured surface engineering of PEEK implants

To improve the bone-implant interface, investigators have coated PEEK and PEEK composites with Ti alloy, as well as with HA [20]. Plasma deposition processing techniques are also compatible with PEEK [21]. Surface modification of PEEK can be by wet chemistry [23,24] and by plasma treatment [25] to improve biocompatibility.

Dental applications of PEEK

Framework Material for Removable Dental Prostheses [26]

For the rehabilitation of partially edentulous patients, the conventional cobalt-chromium frameworks for the construction of removable dental prostheses (RDP) have been a treatment of choice. It has many disadvantages such as display of metal components such as clasps, increased weight of the prostheses and allergic reactions to metals. These disadvantages led to the introduction of alternative materials, one of which being polyetheretherketone (PEEK). A modified PEEK high performance polymer (BioHPP; Bredent GmbH, Senden, Germany) combined with regular acrylic denture teeth and heat-cured denture base acrylic resin can be used as an alternative. The advantages of BioHPP material are, due to its white color and high strength can be used to fabricate metal-free components which are esthetically more pleasing. The elasticity of BioHPP material is 4 GPa modulus of elasticity, which is as elastic as bone. This will reduce the distal torque and the stress on the abutment teeth in cases of distal extension RDPs as the viscoelasticity of the edentulous ridges, exhibit a greater rotation around the supporting rests under occlusal loading. Therefore, it could be hypothesized that BioHPP can be an alternative treatment when restoring distal extension cases.

Interim restoration after implant placement [27]

Resin-bonded fixed dental prostheses (RBFDPs) with a cast metal framework has been a treatment option for interim or long-term restorations. But the main drawback of RBFDPs is debonding because of the high modulus of elasticity of the metal framework and the mobility of the abutment teeth which lead to unfavorable stress concentration at the cement interface.

This led to the use of an alternative material, PEEK which has a lower modulus of elasticity than metal, which could reduce stress concentration at the cementation interface and prevent debonding. Also another method to prevent debonding of metal ceramic RBFDPs, tooth modifications such as axial coverage, retentive grooves, and occlusal rests can be incorporated in the preparation which led to the weakening of the toot structure. But with the use of PEEK framework material it has been observed that there has been increase the longevity of resin-bonded restorations with minimally invasive tooth preparations without retentive elements. Another advantage of the PEEK framework is the high bond strength with the light-polymerized indirect composite veneering materials. Bond strength values up to 25 MPa can be achieved According to DIN EN ISO 10477/Jena University. Because of its white color the grayish appearance of metal frameworks can be eliminated.

***Material for endocrown restorations* [28]**

Endocrowns are widely used in cases of endodontically treated molars with short clinical crowns, short roots, and thin axial walls. But over the years it has been found to have significantly higher fracture strength than conventional crowns restored with a cast post and core or with a fiber post and a resin core. But the high stiffness materials such as alumina can result in excessive loading of the restoration and the abutment teeth. Materials with a lower modulus of elasticity such as PEEK and composite resins have been proved to reduce occlusal stress by acting as stress breakers. As PEEK exhibits a modulus of elasticity of 4 GPa, this can dampen force transmission, preventing the tooth and subsequently the root from overloading and breakage. In addition, PEEK as a core material further reduces the elasticity of the composite resin veneering material from 8 to 10 GPa to 4 GPa. The only disadvantage of PEEK is that the detection of recurrent caries on a radiograph would be a matter of concern as PEEK is a radiolucent material. It can be overcome by periodically evaluating for recurrent caries.

***Use of polyetheretherketone in the fabrication of a maxillary obturator prosthesis* [29]**

Using PEEK for maxillofacial defects is less time-consuming and less complex than using resin or titanium and molding or casting techniques as the physical characteristics of PEEK allows for fracture-resistant thicknesses of 0.5 mm, which is adequate for the hollow bulb technique and for reducing the weight of the prosthesis. The lack of a chemical bond between the acrylic resin and PEEK can be done by carving a groove in the PEEK to provide mechanical retention to the resin and by applying silica microabrasion to permit a chemical-mechanical bond. Hence, construction of an obturator prosthesis using PEEK-Optima is a good alternative to conventional materials and methods.

CONCLUSION

PEEK is relatively a new family of high temperature thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups [30]. Two PAEK polymers, used previously for orthopedic and spinal implants, include poly-ether-ether-ketone (PEEK) and poly (aryl-ether-ketone-ether-ketone-ketone (PEKEKK In the 1990s, researchers characterized the biocompatibility and in vivo stability of various PAEK materials, along with other ‘‘high performance’’ engineering polymers, such as polysulphone (PS) and polybutylene terephthalate (PBT). But, use of these polymers in implants was abandoned for reasons that are not well documented in the literature. Other polyaromatic ketone polymers, such as PEKEKK, were discontinued by their industrial supplier and thus ceased to be available for biomaterial applications. By the late 1990s, PEEK had emerged as the leading high-performance thermoplastic candidate for replacing metal implant components, especially in orthopedics [31]

In the field of dentistry PEEK has been recently introduced to be an alternative treatment option for many conventional methods. But the literature is limited and further studies have to be conducted for PEEK to be the treatment of choice in dentistry in the future.

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