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An overview of applications of PEEK polymer in prosthodontics

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Abstract

The rapid evolution of computer-aided design and computer-aided manufacturing (CAD-CAM) led to the introduction of newer materials that could be precisely milled for the fabrication of dental prostheses. PEEK (PolyEtherEtherKetone) has been explored for a number of applications for clinical dentistry, including removable dental prostheses, fixed dental prostheses, implant-supported prostheses, resin-bonded fixed dental prostheses and implant-retained overdentures. The major beneficial property of PEEK is its lower Young's modulus, and as elastic as bone, providing a cushioning effect and reduction of stress transferred to abutment teeth. It is a material with high biocompatibility, good mechanical properties, high-temperature resistance, chemical stability, polishability, good wear resistance, and high bond strength with luting cements. Further, PEEK is also recommended for a wide range of CAD-CAM fabricated fixed and removable prostheses, fabrication of occlusal splints, intra-radicular posts, implant abutments and provisional restorations. PEEK material shows a property of radiolucency, which is advantageous for the evaluation of both osseointegration and tissue surrounding the implant on computed tomography. Considering these properties, PEEK is increasingly being used in implantology.

Keywords: PEEK, Polymer, Implants, Prosthodontics.

1. Introduction

In view of esthetic concerns, metal-free restorations are gaining popularity in modern dentistry, current advances and improvement in technologies are frequently reached through enhancing materials. Biocompatibility, low plaque affinity, desirable aesthetics, and characteristics on the brink of the dental structure are crucial to current substances utilized in advanced dentistry [1,2]. PEEK (polyetheretherketone) helps in restoring the defects of the teeth and jaws that meet the patient demands, especially in the field of prosthodontics. It has a wide range of applications that include the fabrication of crowns, removable partial dentures, fixed partial dentures, maxillofacial prostheses and implant superstructures. Additionally, it grew to be a crucial high-performance thermoplastic material replacing the metallic implant components used as the interbody fusion cage in a vertebral surgical procedure. With the emergence of a newer material called carbon fibre reinforced PEEK (CF/PEEK), which has been used for fracture fixation and femoral prosthesis within the artificial hip [3].

2. History of PEEK

PEEK is a polyaromatic semi-crystalline thermoplastic polymer and was introduced by Victrex PLC then ICI (Imperial Chemical Industries) in the early 1980s for engineering applications [3]. It was first commercialized for industrial functions for the manufacture of aircraft, turbine blades, piston parts, cable insulation, bearings, and compressor plate valves [4]. Later in 1998, it was proposed for biomedical software through Invibio Ltd (Thornton-Cleveleys, UK). Within a year, Victrex PEEK industrial organization (Imperial industry, London UK) launched PEEK-OPTIMA for long-time period implantable applications [5].

3. Structure and Properties of PEEK

Polyetheretherketone (PEEK) may additionally be a man-made, polycyclic, aromatic, thermoplastic polymer and a member of the PAEK (Poly Aryl Ether Ketone) family. PEEK has desirable mechanical and electrical properties like resistance to heat and resistance to hydrolysis. The main characteristic property of PEEK material is that it has a low elasticity modulus that is close to the bone. PEEK (-C_6H_4-OC_6H_4-OC_6H_4-CO-) n is semi-crystalline and elements a linear structure. This material is obtained because of the binding of ketone and ether functional groups between aryl rings and is a component that gets tan coloured in its pure form. PEEK is also a colourless, radiolucent, rigid material with excellent thermal stability up to 335.8°C [5]. It is non-allergic and has low plaque affinity [5,6]. The flexural modulus is 140 to 170 MPa, density is 1300 kg/m3, and thermal conductivity is 0.29 W/mK [5-7]. Elasticity modulus is 3–4 GPa [8], radiographic radiolucency and low density (1.32 g/cm3), Young's (elastic) modulus of PEEK is 3-4 GPa [7,9]. Young's modulus and tensile strength are on the brink of human bone, enamel, and dentin [10]. Polyether ether ketone is resistant to hydrolysis, non-toxic, and has excellent biocompatibility [11,12]. PEEK's mechanical properties do not change during the sterilization process, the use of steam, gamma, and ethylene oxide.

4. Areas of Use for PEEK

PEEK material was developed by scientists in 1978. In the 1980s, it was mainly used for turbine blades and the aircraft industry. But due to the finest mechanical and electrical properties of the material such as resistance to high temperatures and hydrolysis, its use has been expanded over the years in the automotive, chemical, and electronics industries. Moreover, the properties like high resistance shown to chemical wear, low permeability to radiation, which are regularly modified alongside a number of materials (glass and carbon fibres) extend their use as an alternative to metal alloys in industrial areas [13]. Subsequently, PEEK has been utilized in orthopaedic and trauma cases. The application of PEEK has increased widely within the medical field and showed excellent results, especially when compared to titanium material. It is now introduced to be utilized in dentistry and thus, research has taken an alternative direction [14]. It is thought that PEEK material may be an alternative to standard materials in implantology [15]. As PEEK has high biocompatibility, it's become a material that's utilized in implants, abutments, and prostheses. PEEK material is also used to manufacture screws for bonding with implant abutment. PEEK implants [16]. In implantology, titanium generally has adequate mechanical properties and since it is biocompatible, is accepted because of the primary choice in standard treatments [14]. Metallic implant materials, in particular titanium and alloys, are chosen in implantology due to biocompatibility, resistance to corrosion and mechanical properties. There are some disadvantages like bone resorption and subsequent implant loss, disintegration under radiation light, hypersensitivity reactions, allergic potential and surface deterioration related to peri-implantitis. These disadvantages of titanium implants may be overcome with the utilization of an implant produced from a metal-free material like PEEK [14]. Research in the modification of surface properties of the PEEK material has led to improvement in increased cellular response. Thus, a robust biomaterial has been obtained. Maldonado et al posted a case report showing that hypersensitive reaction was caused due to PEEK material implanted between vertebrae [15].

4.1 Advantages

Compared to the metals used in dentistry, PEEK is more aesthetic, stable, biocompatible, and lighter and has decreased degree of discolouration. This makes it a choice for patients with high aesthetic requirements. However, due to its greyish brown colour, PEEK is no longer suitable for monolithic aesthetic restorations of anterior teeth.

PEEK is a high-temperature thermoplastic and semi-crystalline material. Being radiolucent, PEEK has reduced magnetic resonance imaging artefacts and is very rigid with a flexural power of 140-170 MPa. Another advantage of PEEK is that it does not cause attrition of the opposing natural teeth. peek has good biocompatibility and bio-stability. The modified shape of PEEK is more advantageous for being, non-metallic in taste, excellent polishing properties, low plaque affinity, good wear resistance, antiallergic. It can additionally be used as a choice for RPD framework material when mixed with regular acrylic denture enamel and denture base material. PEEK with its low specific weight can be used to fabricate very light-weight prostheses which will provide high affected person satisfaction and comfort.

5. Applications of peek

The applications of PEEK polymer in prosthodontics include for the fabrication of fixed crowns and bridges, removable dentures, dental implants, implant abutments, and orthodontic wires.

5.1 PEEK crowns

Due to the greyish-brown shade of PEEK, it is not suitable for monolithic aesthetic restorations on anterior teeth. Hence greater aesthetic material like composite should be used as a coating to get an aesthetic result [16]. PEEK requires surface treatments techniques to improve bonding with resin composite crowns. PEEK with surface treatment with 50-micron alumina particles at 0.2- 0.35 MPa followed by etching results increases the tensile bond strength. Many studies confirm that resin composites can be used as a covering material of the PEEK frames. Etching with sulphuric acid creates a rough and chemically altered surface which allows it to bond more efficiently with hydrophobic resin composites (shear bond strength: 19.0 ± 3.4 MPa). It has been found that etching with sulfuric acid for 60–90sec can exhibit shear bond strength to resin composite cements as high as 15.3±7.2 MPa after being stored in water for 28 days at 37.8°C. Etching with piranha acid and using a bonding agent have been shown to produce tensile bond strength to composite resin as high as 23.4±9.9 MPa in aged PEEK specimens. No significant differences have been observed in the tensile bond strength of PEEK crowns and dentin abutments using air abrasion and sulfuric acid etching techniques [13,15]. Some studies suggest PEEK can be used under resin composite as a coping material. Because the mechanical properties of PEEK are similar to dentin and enamel, PEEK could have an advantage over alloy and ceramic restorations [4].

5.2 PEEK as intra-radicular post-core material

PEEK has been tried as intra-radicular post-core material as presented in figure 1. Lee *et al.*, in their study, observed that posts made from PEEK have high fracture resistance as compared to other commonly used post and core materials and there are much fewer possibilities of root fracture when using PEEK [22].

Figure 1. PEEK - Intra-radicular post-core

5.3 PEEK as superstructure for implants

Studies showed that Fatigue strength for BioHPP is very high and can be used as a superstructure for implants. Thus, PEEK can be used as a superstructure for implants retained prostheses shown in figure 2 [16,18].

Figure 2. PEEK implant superstructures

5.4 PEEK in Removable Prostheses

Dentures can be fabricated by using PEEK computer-aided design and computer-aided manufacturing systems presented in figures 3 and 4. However, since the study was performed on metal crowns in vitro, it is not known how effective the esthetic PEEK clasps would be in retaining dentures in the clinical setting [16]. PEEK RPD framework can be well polished and have low plaque affinity, eliminates metallic taste and hypersensitivity reactions, PEEK can be used in the fabrication of removable obturators. Nevertheless, more research is needed to evaluate the efficacy of PEEK obturators compared to traditional acrylic prostheses. To date, no scientific research or systematic reviews focusing on the use of PEEK dentures have been published. However, PEEK owns superior mechanical and biological properties, it will not be surprising if dentures fabricated from the polymer are routinely constructed in future [7]. Clasps made of PEEK show lower retentive forces compared to cobalt-chromium (CoCr) clasps.

Figure 3. PEEK RPD Framework

Figure 4. Removable Partial Denture

5.5 PEEK orthodontic wires

PEEK can be used in orthodontic wire for aesthetics as shown in figure 5. Compared with different types of polymers, such as polyethylene sulfone (PES), polyvinyl difluoride (PVDF), PEEK orthodontic wires provide higher orthodontic strength. Similar orthodontic forces are obtained in comparison with titanium-molybdenum (Ti-Mo) and nickel-titanium (Ni-Ti) wires [23].

5.6 PEEK Implants

Titanium has sufficient mechanical properties; biocompatibility is accepted as the first choice in standard treatments [25]. According to Wolff's Law, the bone remodels according to the load that has been utilized on it [24,26]. Stress shielding is the reduction in quantity and quality of the bone around an implant due to the shielding of normal loads by the implant. Finite element analysis (FEA) of carbon-fibre reinforced PEEK implants recommended

Figure 5. PEEK Orthodontic wire

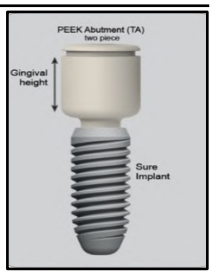

Figure 6. PEEK Implant

recommended that they could result in lesser stress shielding than titanium. However, seeing that PEEK dental implants have not been used widely clinically, it is unknown if there is a difference between the bone resorption around PEEK and titanium implants in human subjects. PEEK implants are presented in figure 6.

Sarot JR *et al.* suggested that there is no significant difference between the stress distribution around titanium implants and peek implants. Indeed, more clinical trials are needed to conclude whether or not PEEK implants produce lesser stress-shielding than titanium implants [26].

Koch F *et al*. demonstrated less bone-implant contact with the PEEK implants compared to zirconium and titanium implants. Because PEEK is made of a bioinert polymer, there is less bone-implant contact, and hence the bone apposition potential is insufficient [27]. PEEK material exhibits extremely limited osteoconductive properties, unlike titanium. Therefore, a significant amount of research has been conducted to increase the bioactivity of PEEK implants. Several modifications to PEEK materials have been attempted to enhance mechanical and biological characteristics. Long-term research on the efficacy of this substance in patients is yet lacking. As a result, PEEK implants aren't commonly used in clinical practice because there isn't enough data to determine their long-term efficacy in human bodies [15].

6. Conclusion

PEEK is a modern material that is employed in dentistry. Because of its high elastic modulus and proximity to bone and dentin, many researchers have looked at using PEEK as an implant material. Increased research into improving the material's bonding with acrylic and composite resins, as well as its osseointegration capabilities, will contribute to more dental applications. PEEK is a future material with exceptional mechanical and biological properties; prostheses made of this polymer will be employed in routine applications, and PEEK material will be used in dental post constructions and endodontics.

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