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Exploring the Potential of PEEK in Prosthetic Dentistry: A Contemporary Perspective

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Abstract

There has been ongoing research to find ideal restorative materials for replacing lost dentofacial structures. Advances in dental materials have provided dentistry with more promising options. Oral conditions require a material with good mechanical, biological and aesthetic properties. Polyetheretherketone (PEEK) is currently one of the viable materials approved by science for restoring lost orofacial tissues. PEEK is a polycyclic, aromatic, thermoplastic polymer with a semi-crystalline and linear structure. It has good mechanical and electrical properties, including resistance to high temperatures and hydrolysis. Its high biocompatibility has led to increased use in orthopaedic and trauma cases. PEEK is a respected dental material and is increasingly replacing metal components in various applications. The polymer has been used in medical devices for decades and offers an impressive range of properties suitable for medical use. Due to its excellent properties, PEEK has several applications in dentistry, including implants, removable and fixed partial dentures, and orthodontic wires. This article explores the potential applications of PEEK in Prosthodontics.

Keywords: Fixed prosthesis, Implants, PEEK, Properties.

1. Introduction

Despite significant research efforts, it is still not possible to claim that there is an excellent material that can meet all the demands of dentists [1]. Therefore, studies are still ongoing regarding the most suitable material and the method for obtaining it [1]. Recent studies have been conducted to address the need for a biocompatible material and to eliminate aesthetic concerns. As a result, PEEK material has been developed with superior mechanical and aesthetic properties that suit this material to use in dentistry [2]. PEEK is a polycyclic, aromatic, thermoplastic polymer that is semi-crystalline and has a linear structure. This material is obtained as a result of the binding of ketone and ether functional groups between aryl rings and is an element which is tan coloured in its pure form [3].

In contemporary dentistry, metal-free restorations are becoming more popular due to aesthetic concerns. One of these restorations is PEEK, which has numerous potential applications in dentistry [4]. PEEK is gaining importance in oral implantology and prosthodontics because of its excellent properties.

Titanium 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 metallic colour, which is less acceptable in aesthetic regions [4]. PEEK-based materials can be considered viable substitutes for titanium to address these problems [5]. Due to its excellent mechanical and aesthetic properties, PEEK can also be used as a framework for removable and fixed dental prostheses [6]. This review explores the contemporary application of PEEK in prosthodontics.

2. History of PEEK

PEEK is a semi-crystalline thermoplastic polymer, which was introduced by Victrex PLC in 1980 [1]. PEEK was initially used for industrial purposes such as in aircraft manufacturing, turbine blades, piston parts, cable insulation, bearings, and compressor plate valves [1]. In 1998, it was also adapted for biomedical applications, and Victrex PEEK business launched PEEK-OPTIMA for long-term implantable use in the same year [7].

3. Structure of PEEK

PEEK is a colourless organic thermoplastic polymer a member of the PAEK family. It is a homopolymer having a single monomer as shown in Figure 1 [8]. PEEK is a semicrystalline thermoplastic with exceptional chemical and mechanical properties that are even retained at higher temperatures [8]. Length, chemical composition, and structure of PEEK renders it stable at high temperatures making processing of PEEK implant components easy.

PEEK shows resistance to deterioration during various sterilisation procedures; hence, it can be heat sterilised without affecting its properties [9]. The chemical structure of PEEK makes it highly resistant to chemical and radiation

damage, compatible with reinforcing agents such as glass and carbon fibres and imparts greater strength than metals. These properties make this material highly suitable for industrial applications [10].

PEEK is widely used not only in engineering applications but also in medical applications due to its excellent thermal properties, superior wear resistance, great processability, inertness, corrosion resistance, high strength, and modulus of elasticity [8]. PEEK has a similar elastic modulus to human bone, suggesting homogeneous stress distribution to the surrounding tissues. Its radiographic radiolucency and low density (1.32 g/cm^3) make it suitable for medical applications [8].

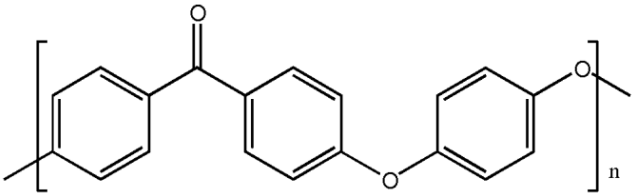

Figure 1. The chemical structure of PEEK material

4. PEEK processing and manufacturing

PEEK implant components are manufactured using injection moulding, extrusion and compression moulding techniques. As an alternative to these techniques, rapid Prototyping and CAD-CAM milling produce quick, highly precise prostheses without compromising the quality of the material [11].

5. Why is PEEK an effective dental material?

5.1 Biocompatibility

PEEK's biocompatibility has been proven, and the research has confirmed its non-toxicity. PEEK is the ideal choice compared to metal, which can cause allergic reactions. PEEK components are found in spine implants, trauma fixation devices, hip and knee arthroplasty, and other medical devices. In every instance, there have been no issues with PEEK's safety in the body [12].

5.2 Mechanical properties

PEEK has a superior strength-to-weight ratio, making it the material of choice for dental implants and devices. Compared to metal, PEEK is lighter and more comfortable for patients. It can withstand abrasive and compressive forces without losing its integrity. Additionally, this polymer is resistant to corrosion and absorbs water at a minimal rate, allowing it to maintain its performance for years [12]

5.3 Ability to be machined

Dentists are increasingly relying on Computer-Assisted Design (CAD) and Machining (CAM), making PEEK a perfect fit for these processes. Modern dental devices require a precise fit with the patient's anatomy, and CAD/CAM is necessary to achieve this. When PEEK is machined to manufacturer specifications, it retains its properties after milling. PEEK's easy compatibility with CAD/CAM methods means it can be processed quickly and consistently [12].

5.4. Flexibility

This durable high-performance polymer is not stiff. Without fillers, it provides a modulus similar to cortical bone, making PEEK a flexible and strong dental material. Because of its added flexibility, PEEK will feel natural in the mouth and retain its resilience even after years of biting and chewing. Dental appliances must retain their shape despite enduring constant stress [12].

5.5. Radiolucency

The ability of PEEK to appear radiolucent on radiographs is a valuable characteristic when the material is utilized in implant procedures. Once implanted, the polymer will not cause any visual obstruction on X-rays, CT, or MRI scans. Since X-rays are crucial for dental diagnosis, PEEK's non-opacity in images will enable dentists to effectively monitor their patients' health. In situations where PEEK's excellent radiolucency might be perceived as a drawback, the polymer can be enhanced with substances such as Barium Sulfate to improve contrast [12].

5.6. Aesthetics

PEEK is an easy dental material to integrate into the oral cavity, as its colour can be modified during processing. Even full dentures can be fabricated to appear natural, ensuring patients can speak, smile and eat with confidence [12].

5.7. Taste neutral

The use of metal devices can lead to a metallic taste for many patients, which is not a health risk but can be an ongoing source of annoyance for those who would prefer not to be constantly reminded of their dental prosthetics. Fortunately, PEEK is a taste-neutral dental material, providing patients with an additional level of comfort that is not achievable with metal devices [12].

6. Applications of PEEK in prosthodontics

The exceptional properties of PEEK enabled its successful use as a biomaterial in medicine and led to its subsequent application in dentistry. Various surface modifications have facilitated the bonding of PEEK with different luting agents.

6.1 Implants

Dental implants make one of the most viable replacements for missing teeth. Titanium has been the material of choice for dental implants since it was introduced by Branemark [5]. However, titanium lacks certain important properties. The difference in elastic moduli of Titanium and surrounding bone leads to stress shielding and bone resorption [5]. One of the main benefits of using PEEK as an implant material is its Young's modulus, which is similar to that of human bone. Consequently, it can create beneficial stress and deformations that minimize the effects of stress shielding and bone resorption [5].

The unfilled form of PEEK has an elastic modulus of 3-4 GPa. The addition of reinforcing agents like carbon fibres increases elastic modulus of PEEK up to 18 GPa which matches the elastic moduli of bone (14 GPa) [13]. Titanium can cause a dark glint in the surrounding implant tissue when used in patients with thin biotype and mucosal recession, resulting in an unattractive appearance, particularly in patients with a high lip line. In such scenarios, PEEK can serve as an alternative to titanium [14].

PEEK is a biologically inert material with limited biological properties, such as restricted bone fixation. This lack of

bioactivity can be addressed by treating the material with plasma modification to increase its bioactivity [15]. Plasma modifications have been shown to induce osteogenic differentiation, proliferation, and adhesion. In addition, various chemical processes, such as sulfonation, titanium dioxide surface coating, and gold coating, have also been investigated for this purpose [15]. Research has focused on applying hydroxyapatite (HA) coating to enhance cell attachment to the surface of PEEK implants. Studies have demonstrated that PEEK implants coated with HA exhibit better results compared to non-coated PEEK implants [16].

The researchers found different tissue activity and cytokines related to inflammation around different implant materials through histological analyses [15]. Titanium-aluminium-vanadium alloys show higher levels of alkaline phosphatase and osteocalcin nearby, but DNA presence is less visible around PEEK implants [16]. Nevertheless, it has been observed that the levels of the proinflammatory cytokines IL1-ß, IL-6, and IL-8 are elevated around PEEK implants and titanium alloys, at the very least. Titanium alloys have higher levels of the anti-inflammatory cytokine IL-10 compared to PEEK [15]. The production of these proinflammatory cytokines is responsible for developing fibrotic tissue around PEEK implants. Conversely, titanium alloy surfaces provide a more favourable environment for osteogenic activity [17].

6.2 PEEK as abutments

Various materials have been experimented as abutments including, titanium (Figure 2a), zirconia, ceramics, and gold. However, titanium has certain drawbacks such as corrosion, which can lead to hypersensitivity reactions [17]. Further, if the aesthetics are a priority, the conclusions are not entirely satisfactory. Zirconia has been utilized as an abutment, but its corrosive nature and weak mechanical properties restrict its use, especially when compared to PEEK (Figure 2b), which has superior mechanical properties and can serve as both an abutment and prosthetic material [17]. The elastic quality of PEEK reduces the pressures generated during chewing and transmission, it has been suggested that forces occurring at the tooth abutment and the cement contact are exaggerated concerning the implant due to the low elastic modulus of this material [18].

Figure 2. a. Titanium abutment and b. PEEK (Elegance) abutment.

6.3 PEEK in fixed prosthesis

PEEK can be veneered with composites because of its opacity to achieve aesthetics [19]. Adding appropriate pigments can modify PEEK's natural grey colour in unfilled material. PEEK is chemically inert, hence many techniques including, sandblasting, the locate process, surface etching with sulfuric acid, and piranha solution (a mixture of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2)) have been attempted to achieve a strong bond with veneering materials [19, 20]. A more recent technique, plasma surface modification, enables surface activation, cross-linking, and removal of organic residues [19]. PEEK's surface has been altered to adhere to various luting agents. Utilizing multifunctional methacrylates containing resin varnish on air-abraded PEEK surfaces has shown promise in establishing a durable bond to PEEK, rendering it suitable for use in clinical settings [20].

6.4 PEEK in removable prosthesis

PEEK is also suitable for making clasps and dentures with CAD/CAM systems due to its lightweight and superior biological, cosmetic, and mechanical properties [21]. It can also be used for making removable obturators. The palatal section of maxillary obturator prostheses can utilize PEEK-OPTIMA (reinforced poly-ether-ether ketone) because of its biological compatibility, durability, torsional bone modulus, machinability, and easy processing [21]. In addition to shock-absorbing during mastication, PEEK frameworks offer remarkable resistance to deterioration and abrasion [22]. Even though metals have considerable strength, patient comfort, and resilience are also major concerns [22]. Despite having strong fracture resistance, homogenous PEEK has poor mechanical properties. Tannous *et al.* demonstrated lower resistance forces with the PEEK clasps than cobalt-chrome" [23]. This led to the development of a modified PEEK known as BioHPP (Bredent GmbH, Senden, Germany) that contains 19.97% ceramic fillers. High-quality prostheses are produced using BioHPP due to their capacity to be corrected, good stability, ideal polishing ability, and aesthetics. In patients with high aesthetic demands, BioHPP has enormous promise as a framework material and is a promising alternative to Cr-Co frameworks [24].

PEEK has high resistance and is white, making it suitable for preparing metal hooks and braces. It can also be utilized as a material for implant-supported bars [25,26] and combined with acrylic teeth for removable partial prostheses. PEEK is a long-lasting restoration method due to its low solubility and water absorption [26,27].

7. Conclusion

PEEK is a modern material attracting interest for use in dentistry. Due to the high elastic modulus close to that of bone and dentin, there is increasing use of the material in implantology. It can be considered that increasing the bonding of the material with acrylic and composite resins and developing the osteointegration properties will further increase dental applications. The superior mechanical and biological properties of PEEK make it a promising material for future use in the fabrication of various prostheses, with a potential for applications in dental post structures in the field of prosthodontics.

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