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Review

Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics

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Purpose: Polyetheretherketone (PEEK) is a polymer that has many potential uses in dentistry. The aim of this review was to summarize the outcome of research conducted on the material for dental applications. In addition, future prospects of PEEK in the field of clinical dentistry have been highlighted.
Study selection: An electronic search was carried out *via* the PubMed (Medline) database using keywords 'polyetheretherketone', 'dental' and 'dentistry' in combination. Original research papers published in English language in last fifteen year were considered. The studies relevant to our review were critically analyzed and summarized.
Results: PEEK has been explored for a number of applications for clinical dentistry. For example, PEEK dental implants have exhibited lesser stress shielding compared to titanium dental implants due to closer match of mechanical properties of PEEK and bone. PEEK is a promising material for a number of removable and fixed prosthesis. Furthermore, recent studies have focused improving the bioactivity of PEEK implants at the nanoscale.
Conclusion: Considering mechanical and physical properties similar to bone, PEEK can be used in many areas of dentistry. Improving the bioactivity of PEEK dental implants without compromising their mechanical properties is a major challenge. Further modifications and improving the material properties may increase its applications in clinical dentistry.

Contents

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1. Introduction

Polyetheretherketone (PEEK) is a synthetic, tooth colored polymeric material that has been used as a biomaterial in orthopedics for many years [1–3]. The monomer unit of etheretherketone monomer (Fig. 1) polymerizes *via* step-growth dialkylation reaction of bis-phenolates to form polyetheretherketone. A common synthesis route for PEEK is the reaction between 4,4′-difluorobenzophenone and the disodium salt of hydroquinone in a polar solvent such as diphenyl sulphone at 300 °C. It is a semicrystalline material having a melting point around 335 °C. PEEK can modified either by the addition of functionalized monomers (pre-polymerization) or post-polymerization modifications by chemical processes such as sulphonation, amination and nitration [4].

The major beneficial property for orthopedics implant application remains its lower Young's (elastic) modulus (3–4 GPa) being close to human bone [5]. PEEK can be modified easily by incorporation of other materials. For example; incorporation of carbon fibers can increase the elastic modulus up to 18 GPa [5]. The titanium and its alloys have elastic modulus significantly higher than bone and resulting in severe stress-shielding and failure [6]. The modulus of carbon-reinforced PEEK is also comparable to those of cortical bone and dentin [7,8] so the polymer could exhibit lesser stress shielding when compared to titanium which used as an implant material (Table 1). Moreover, tensile properties of PEEK are also analogous to those of bone, enamel and dentin [9–12], making it a suitable restorative material as far as the mechanical properties are concerned.

In contrast to titanium, PEEK has very limited inherent osteoconductive properties [17]. Hence, a considerable amount of research has been conducted to improve the bioactivity of PEEK implants [18–22]. There are a number of methods that have been proposed to improve the bioactivity of PEEK including coating PEEK with synthetic osteoconductive hydroxyl apatite [18,23], increasing its surface roughness and chemical modifications [24] and incorporating bioactive particles [25]. PEEK has white color and excellent mechanical properties, hence it has been proposed for other prosthodontic applications such as fixed prostheses [26] and removable prostheses [27]. The effects of surface modification of PEEK have been investigated for bonding with different luting agents [26,28] and extracted teeth [29]. The potential of PEEK for various dental applications has been shown in Fig. 2. Moreover, PEEK can also be used an esthetic orthodontic wire. Compared to other polymers, such as polyether sulfone (PES) and polyvinylidene difluoride (PVDF), PEEK orthodontic wires are able to deliver higher orthodontic forces but at a cross-section of that similar to metallic wires such as cobalt–chromium (Co–Cr), titanium–molybdenum (Ti–Mo) and nickel–titanium (Ni–Ti) [30]. Due to these unique physical and mechanical properties, PEEK is a promising material for dental applications. The aim of this review is to summarize the outcome of research conducted on the material for prosthodontic applications. In addition, future prospects of PEEK in the field of clinical dentistry have been highlighted.

2. PEEK as an implant material

According to Wolff's Law, the bone remodels according to the load that has been applied to it. Stress shielding is the reduction in volume of the bone around an implant due to the shielding of normal loads by the implant. Finite-element analysis (FEA) of carbon-fiber reinforced PEEK (CFR-PEEK) implants suggested that they could induce lesser stress shielding than titanium [6]. However, since 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. Moreover, a more recent FEA study by Sarot et al. suggests there is no difference between the stress distribution around PEEK and titanium dental implants [31]. Indeed, more clinical trials are vital to conclude whether or not PEEK implants produce lesser stress-shielding than titanium implants.

Unmodified PEEK is inherently hydrophobic in nature, with a water-contact angle of 80–90° and bioinert [32,33]. Indeed, studies have shown that there is no significant effect of unmodified PEEK on the proliferation rate of cells *in vitro* [34]. On the contrary, some studies have observed an increased protein turnover in cells in contact with conventional- and CFR-PEEK [35]. Animal studies have suggested that PEEK can survive for up to 3 years while inducing non-remarkable localized inflammation [33]. Nevertheless, quite a few studies suggested that there is no significant difference between the osseointegration of PEEK and conventional implant materials such as zirconia and titanium [36,37]. Conversely, recent proteomic studies have indicated that PEEK inhibits mRNA processing that may lead to a decreased cellular proliferation rate on the surface and cytotoxic effects may be produced in the long-term [38]. Nonetheless, the same proteomic studies have found no difference between the bioinertness of PEEK, zirconia and titanium [38]. Although unmodified PEEK, is considered as a biointert material however, there has been no conclusive evidence of osseoconductive effects of PEEK *in vivo* and *in vitro*. Hence, in its unmodified form, the long term survival rate of PEEK implants is questionable.

In order to improve the mechanical and biological properties, a number of modifications have been attempted in PEEK materials. However, PEEK dental implants have not been extensively used clinically and there is insufficient data to deduce their long-term efficacy in human subjects.