IDR International Dental Research

Review Article

Areas for use of PEEK material in dentistry

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Abstract

Polyetheretherketone (PEEK) material is a polycyclic, aromatic, thermoplastic polymer that is semi-crystalline and has a linear structure. PEEK has good mechanical and electrical properties such as resistance to high temperature and resistance to hydrolysis. In addition, because of the property of high biocompatibility, use of PEEK has increased in orthopedic and trauma cases. The most characteristic property of PEEK material is that it has a low elasticity modulus, close to that of bone. It has been suggested that stress-based problems could be reduced with this material due to the low elasticity modulus. In the light of this information, PEEK material could be considered as an alternative to conventional materials in the field of dentistry.

Keywords: Polyetheretherketone, PEEK, polymer, dental application, dental implant

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Received: 7 March 2018
Accepted: 11 May 2018

Access Online
Quick Response Code

DOI:
10.5577/intdentres.2018.vol8.no2.6

How to cite this article: Tekin S, Cangül S, Adıgüzel Ö, Değer Y. Areas for use of PEEK material in dentistry. Int Dent Res 2018;8(2):84-92.

Introduction

Despite great efforts made in research, it is still not possible to say that there is an excellent material that can meet all the demands of physicians. Therefore, studies are still ongoing in respect of the most suitable material and the method of obtaining this material (1). In recent studies conducted to meet the need for a biocompatible material and eliminate aesthetic expectations, polyetheretherketone (PEEK) material has been developed with the aim of benefitting from the mechanical and aesthetic properties 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-colored in its pure form (3) (Figure 1).

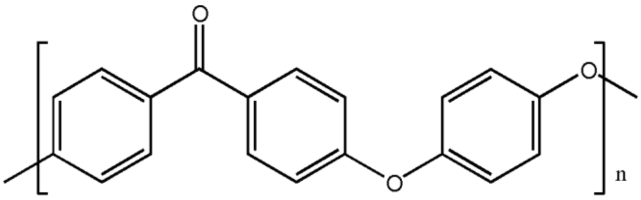

Figure 1. The chemical structure of PEEK material.

The Properties of PEEK Material

This material, which can be produced by casting under heat and pressure with CAD-Cam technology and the wax waste management method, has several positive properties. These are:

It shows resistance to hydrolysis, has superior mechanical properties and is resistant to high temperatures.

When PEEK material and components are examined, no evidence has been shown of cytotoxicity, mutagenicity, carcinogenicity or immunogenicity in the toxic form (4).

It is a biologically inert material.

It shows resistance to deterioration during various sterilization procedures (5). Melting point is >280°C. Therefore, it can be processed with hot sterilization methods.

It shows high resistance to chemical wear.

It can be modified together with various materials.

The most important property of this material is that it has a low elasticity modulus (close to the elasticity modulus of bone) (6). (Table 1.)

When an increase in the elasticity modulus is desired, the PEEK elasticity modulus can be brought to high levels with the addition of carbon fibers.

It is a very light material (27) with a low density (1.32g / cm3) (7,8).

It allows magnetic resonance imaging (MRI) (9).

Radiation heat does not cause disintegration.

Laboratory stages are simple.

It is a low-cost material that can be easily prepared within the mouth.

Table 1. Elasticity modulus of different structures and materials (6)

	Elasticity modulus	Reference
Cortical bone	13.7 GPa	(11, 12, 13)
Spongeous bone (Type 3)	1.37 GPa	(14, 15, 16)
Dentin	14.7 GPa	(17, 18)
Titanium Implant and Abutment	110 GPa	(11, 12, 13)
Chrome-Cobalt Alloy	218 GPa	(19, 20)
Feldspathic Porcelain	82.8 GPa	(20, 21, 22)
Zirconium	200 GPa	(17, 23)
PEEK	3-4 GPa	(8, 24, 25)
CFR-PEEK	19-150 GPa	(26)

Areas of Use for PEEK Materials

PEEK material was first developed by English scientists in 1978 (3). In the 1980s, the commercial process was started with the aim of industrial use, such as for turbine blades and in the aircraft industry. Due to the superior mechanical and electrical properties of this material, such as resistance to high temperatures and hydrolysis, it has been widely used for many years in the automotive, chemical and electronics industries. Moreover, the positive properties such as high resistance shown to chemical wear, low permeability to radiation and that it can be modified together with various different materials (glass and carbon fibers) increase its use as an alternative to metal alloys in industrial areas (10).

Subsequently, PEEK has been used in orthopedic and trauma cases (5). The use of PEEK has become extremely widespread in the medical field and excellent results have started to be seen at a competitive level with the titanium material in particular. It is currently thought that the material could be used in dentistry and therefore, studies have taken a new direction (11).

The Use of PEEK Material in Dental Implantology.

It is thought that PEEK material could be an alternative to conventional materials in implantology (12). As PEEK has shown high biocompatibility in dentistry, it has become a material that is used in implant, abutment and prosthesis production. Under the headings of healing from PEEK material in implantology, it is also possible to manufacture screws providing bonding with implant abutment (8).

PEEK Implants

Together with the concept of osteointegration defined by Branemark et al, titanium implants started to be used in dentistry, and due to the successful results obtained, are still used today (13, 14, 15). In implantology, titanium generally has sufficient mechanical properties and as it is biocompatible, is accepted as the first choice in standard treatments (16). Metallic implant materials, especially titanium and alloys are selected in implantology because of biocompatibility, resistance to corrosion and mechanical properties. Despite several advantages of these materials, there are some disadvantages such as bone resorption and subsequent implant loss, disintegration under radiation light, over-sensitivity reactions, allergic potential and surface deterioration related to peri-implantitis. It is predicted that these negative aspects that can be seen in titanium implants could be overcome with the use of an implant produced from a non-metallic material such as PEEK (17).

Research into the implantability of PEEK material is based on information of the 1980s. In surface modification studies, surface properties of the PEEK material have been developed to increase the cellular response. Thus, a strong biomaterial has been obtained. A case report published by Maldonado et al showed that allergy was caused by PEEK material implanted between vertebrae (18). As PEEK material has very low water solubility, the response to the material, especially in allergic patients, is extremely low compared to several other materials. That it does not disintegrate under radiation light is another property of PEEK material that makes it an alternative to metallic implants (3).

As titanium has a high elastic modulus, shock absorbency is not shown during chewing actions (19). It has been suggested that as PEEK material has an elasticity modulus close to that of bone, the stresses occurring on the bone are reduced with the absorption of forces. Transfer onto the bone of the loading on a rigid structure implant leads to resorption in the bone. It has been claimed that due to the shock absorbing property of PEEK material, there is the advantage of bone protection (20).

In studies by Schwitalla et al, it was reported that there had been insufficient studies to develop the biomechanical behaviour to provide a more homogenous stress distribution of PEEK implants to the perimplant bone, and there was a need for further long-term studies of PEEK implants (21). Sarot et al compared the stresses occurring on the bone of PEEK and titanium implants and no significant difference was observed between the groups (22).

In respect of the success of osteointegration, studies that have compared PEEK with conventional implant materials such as titanium and zirconium have emphasized that there was no significant difference (21, 23). In a study by Toth et al, PEEK implants were applied with autograft or rhBMP-2, and after 6 months, histological integration with sheep bone was observed. However, it was not reported whether this integration had occurred with micromechanical integration rather than a chemical relationship (24).

Previous studies have reported that 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 (25). Primary of these are studies of surface roughening.

Koch et al compared the bone-implant contact values of PEEK, zirconium and titanium implants, and the PEEK implants were observed to have the lowest values. The reason for this was reported to be that PEEK is formed of a bioinert material and thus the bone apposition potential was insufficient (23).

In a study by Cook et al, PEEK implants strengthened with carbon fiber (CFR-PEEK) and titanium covered CFR-PEEK implants were implanted to femurs and evaluated after 8 weeks. Similar bone-implant contact ratios were reported (26).

To increase cell attachment in the PEEK implant surface, studies have been made on hydroxyapatite (HA) coating. Promising results have been obtained from PEEK implants coated with HA in comparison with non-coated PEEK implants (27).

When current research is examined, it can be seen that there are still no long-term studies of the efficacy of this material on patients. Therefore, PEEK implants are not widely used clinically (11).

PEEK Abutments

Implant supported treatments and the osteointegration of implants are important topics. Moreover, the abutment has to be a material that meets the mechanical, biological and aesthetic expectations (28, 29). Various materials such as titanium, gold, zirconium and ceramics are made use of in the production of abutments (30). Although titanium and alloys have several disadvantages such as corrosion and causing over-sensitivity reactions, they are the most frequently selected materials in the production of implants and abutments and have been accepted as the gold standard (31). However, sometimes in cases where aesthetics are a priority, satisfactory results cannot be obtained. Aesthetic problems are seen particularly where there is the presence of gingival tissue of a fine biotype. In addition, gold is a material with a low possibility for use in respect of costs (30). Zirconium abutments become worn intraorally over time. In addition, as the mechanical resistance is not good, this causes changes in the internal structure. This material is characterized by disadvantages such as deterioration in water and water solutions and at low temperatures, and transition from a tetragonal phase to a monoclinic phase. Results of in vitro and in vivo studies have shown that the use of aluminum and zirconium ceramic abutments is limited with full ceramic prosthesis over a single tooth implant (32).

Figure 1. Detail of materials used in the experimental protocol. (a) Bredent Blue Sky Narrow Implant®. (b) Titanium abutment. (c) Peek (Elegance) abutment. (J.E. Maté Sánchez de Val et al. / Annals of Anatomy 206 (2016) 104–109 (33))

When the difficulties are considered of situations of implant screw breakage, screws made of PEEK can be removed more easily. The tests applied have shown that PEEK material is resistant up to 1200N of chewing forces (34). As the elastic property of PEEK material reduces the forces created when chewing which are communicated to the implant, it has been claimed that because of the low elastic modulus of this material, the stresses occurring both in abutment teeth and in the cement interface are reduced to a minimum (7). It is thought that the stress-based problems of PEEK in implantology could be overcome. Furthermore, because of the high mechanical properties, it has been advocated that this material can be used both as an abutment and prosthetic material (30). However, there are very few studies that have analyzed the stress created in this material.

It has been suggested that PEEK can promote the bone remodeling process. Therefore, it has been reported that this material could be a suitable alternative to titanium in abutment production (Fig. 2 and 3) (11).

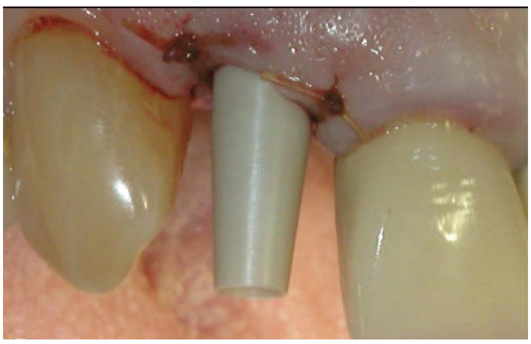

Figure 2. A new transitional abutment for immediate aesthetics and function (21)

Figure 3. Use of high performance polymers as dental implant abutments and frameworks: a case series report (21)

Schwitalla et al reported that the stress values occurring around the bone were lower in a group using titanium abutment compared to the group with PEEK abutment (35).

In a study by Hendrik, composite resin crowns were applied over PEEK and titanium temporary abutments and the breaking resistance of these were compared. The crowns applied over the PEEK abutments were seen to have lower resistance (36).

PEEK material that can also be produced with a titanium base is a flexible material. According to the research, when PEEK abutments were compared with zirconium abutments, while no breakage was encountered in the zirconium abutments, there was deformation in the PEEK abutments but no breakage. Breakage in metal and zirconium abutments is not in the abutment itself, but is seen in the holding screws, whereas in ceramic abutments, breakage is observed in the abutment itself. The semi-crystalline structure of PEEK reduces fragility, and therefore rather than breakage, deformation is seen. Consequently, in problems occurring in upper structures, PEEK abutments can be easily changed and problems which could arise because of the difficulty of removing a broken screw can be avoided. In one study, no breakage was determined in 40% of prostheses applied over PEEK abutments and only deformation in the abutment was observed. Therefore, it was reported that with only a change of abutment, the same prosthesis can be used again (37).

The Use of PEEK Material in Fixed Prostheses

In implant supported prosthetic systems the upper structure is formed of crown materials. Metal supported ceramics have been used for many years in dentistry and the results obtained have shown them to be successful. However, there are some disadvantages. Metal alloys can undergo corrosion and have the potential to cause allergies. Furthermore, the lack of light permeability is one of the negative properties of metal alloys (38).

The biocompatibility of PEEK material is higher than that of metal-based ceramics. However, there are researchers who have claimed that it should be covered with veneer as it is not sufficiently clear (39). As PEEK is lighter, it may be a suitable alternative to chrome-cobalt ceramics. Furthermore, it does not corrode when in contact with other metals in the mouth (34). PEEK is not soluble in water and has a low reactivity with other materials, so could, therefore, be a suitable alternative for patients with a metal allergy or who are sensitive to metallic taste (40).

As PEEK material can be more easily repaired than ceramics, does not wear down within the mouth and no deterioration is seen in the material properties during processing, this increases the possibility of its use as crown material. Moreover, despite the low elasticity modulus and hardness, the high resistance to wear makes this a material that can compete with metallic alloys (41).

In previous studies, it has been suggested that 3-unit PEEK prostheses produced with CAD-CAM have higher breakage resistance than granular -pressed or pellet-shaped PEEK prostheses. The resistance to breakage of PEEK fixed prostheses ground with CAD-CAM is higher than that of lithium disilicate glass-ceramic, aluminum, and zirconium.

Bonding of PEEK Material to Composites

One of the major advantages of PEEK material is that it can bind to indirect composites polymerized with light. To meet aesthetic requirements, this material which shows low half lucency can be coated with composite resins (42).

In resin-bonded bridges produced from PEEK material, there is a minimal need for holding elements and retentive abrasions as in metal ceramic resin-bonded prostheses (40).

In the use of PEEK material as a temporary abutment, high bonding is required between composite resins in the formation of the gingival tissue emergence profile and the gingiva shaping (43).

To achieve good bonding between PEEK and composite, cleaning and roughening of the surface is generally recommended. In most cases, the application of opaque material is known to increase resistance to shear forces. Successful bonding on PEEK surfaces is provided as a result of surface activation with roughening followed by processing with acetone, phosphate-based methacrylate linings or tribochemicals (44).

PEEK fibers exhibit extremely strong resistance to most chemical substances and are only affected by some high concentration acids (sulfuric acid, nitric acid). Previous studies have shown that acidification with H_2SO_4 or a combination of H_2SO_4 and H_2O_2 applied to the PEEK surface was insufficient in the bonding of composites with PEEK material. The range of current surface processes and application times have yielded conflicting results in respect of shear forces (44).

Rocha et al reported that sulfuric acid only or a mixture of sulfuric acid and hydrogen peroxide can be used to roughen the PEEK surface and with sanding on the PEEK, the surface area and wettability can be increased (45).

Various adhesive systems are used to increase the bond between composite resins and PEEK. Stawarczyk et al. reported that the use of Visolink and Signum PEEK Bonds significantly increased the bond between composite resins and PEEK (46).

In a study by Taufell et al, it was concluded that there were advantages such as resistance to wear, standardization, polymerization, low coloration and monomer content of the veneer process made using the CAD-CAM method compared to manual coating (47).

The Use of PEEK Material in Removable Prostheses

PEEK is used in dentistry as an alternative to metal braces and hooks in removable partial prostheses. In comparison with chrome-cobalt-based partial prostheses, PEEK hooks have been shown to have lower retentive strength (48).

They eliminate metallic taste and allergic reactions, can be well polished and have low plaque retention. As PEEK is white in color and has high resistance, it can be used in the preparation of metal braces and hooks (49).

It can be used in implant supporting bars.

In combination with high-performance polymer, PEEK can be used with acrylic teeth as an alternative removable partial prosthesis material (49).

It is thought that prostheses with PEEK substructure could benefit the health of the tooth in removable partial prostheses with distal extension. The elasticity of the material could reduce torque force and the stress on the tooth. Consequently, lighter prostheses can be obtained which increase patient satisfaction and comfort.

Changes in the color of PEEK have been observed to be more stable compared to other prosthesis resin materials. The effects have been compared on surface roughness and free surface energy of polishing methods applied in the clinic and laboratory to PEEK, PMMA and a composite resin. Lower surface roughness and free surface energy were obtained in PEEK, which is a harder material (50).

There are several advantages of PEEK material as the substructure in fixed and partial prostheses. These include that it can be more easily produced compared to metal substructure, and those produced with CAD-CAM systems can be more easily applied with abrasion in a short time without damaging the burrs (51).

As a result of previous research, it has been reported that PEEK material can be recommended for long-term restorations because of low water absorption and solubility properties (52).

PEEK Orthodontic Wires

PEEK can be used as aesthetic orthodontic wire. Compared with other polymers, such as polyethylene sulfone (PES) and 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 (53).

Studies directed to the development of PEEK Materials

PEEK material can be easily modified. Several materials can be used in this modification. Particularly following modification with carbon fiber and glass fibers, resistance to wear has been seen to have developed and superior mechanical properties (17). As a result of modification of PEEK with varying rates of titanium dioxide, barium sulfate, carbon fiber, and glass fiber, it can be a material with advanced resistance to wear, high durability and hardness (54).

As PEEK does not have sufficient lucidity, there are researchers who state that coating with veneer is necessary. The color and superior mechanical properties allow the use of PEEK as an alternative substructure material to metal alloy and zirconium dioxide (55). The veneer coating procedure increases the aesthetics. Before the procedure, alumina particles 110μm in size are applied under pressure to the outer surface of the material. Due to the low elasticity modulus of PEEK, the use of composite resin polymerized with light as veneer material provides a reduction of occlusal forces. In addition, PEEK is seen to be more advantageous than metal supported ceramic restorations in the reduction of differentiation ratios of composite resins (40). Both monolithic and veneer-coated PEEK has been reported to be able to be used for prosthetic restorations (37).

In a study in which mechanical tests were applied to prostheses produced from zirconium, metal, ceramic and PEEK materials, it was reported that composite-coated PEEK had lower fracture resistance to occlusal forces than metal ceramic and zirconium restorations. Furthermore, the fractures in the PEEK restorations were seen to be between the PEEK substructure and the composite veneer (56). When the veneer material is fractured in PEEK material, repair procedures can be intra-orally applied easily with traditional composite resins to restore the aesthetic appearance (40).

As PEEK material has the property of radiolucency, this is an advantage in the evaluation of both osseointegration and of the tissue surrounding the implant on computed tomography (CT) imaging (17). Radiolucency facilitates the determination of peri-implant cement remains. However, the radiolucence of PEEK makes the evaluation of the compatibility of PEEK prostheses with screw retention more difficult on radiographs (30). To be able to observe PEEK material on radiographs more easily, in other words to increase the radio-opacity, barium sulfate must be added (17).

Dual cure resin cements are used for the cementation of PEEK materials. One of the main disadvantages of PEEK material in prosthetic dentistry is the low surface energy. PEEK shows low bonding to resin cements (39). One of the main reasons for the loss of cement bonding is the high flexibility modulus of metal substructures and another is the negative stress concentration in the cement interface which leads to abutment tooth movement (57). To eliminate this problem, PEEK surface energy is increased using traditional sanding, roughening with acid, plasma spray and laser roughening methods (58). In a study by Schmidlin et al, resin systems were reported to be successful in PEEK restorations, but it was recorded that no bonding was seen apart from the acidified surface (59). It has also been shown that surface energy was not increased and no bonding or very little occurred between PEEK material and resin cements (60).

To overcome the limited bioactivity of PEEK, to improve mechanical and biological properties and to increase surface roughness, PEEK can be blended with or coated with bioactive particles at the nanometer level. These methods are spin-coating, gas plasma etching, electron beam, and plasma-ion immersion implantation. In addition, increased bioactivity can be achieved with fusion with the addition of TiO_2 and HA to PEEK material (61).

Nevertheless, it is emphasized that there is a need for more experimental studies to confirm the suitability of the use of these implants as dental implants.

Conclusions

PEEK material is a modern material attracting interest for use in dentistry. Due to the high elasticity 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.

Due to the superior mechanical and biological properties of PEEK material, it can be considered that in the future, prostheses made from polymer will have a place in routine applications and PEEK material will be used in dental post structures and the field of endodontics.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception - S.T; Design - S.C., Ö.A.; Supervision - Ö.A.; Materials - S.C.; Data Collection and/or Processing - Ö.A., Y.D.; Analysis and/or Interpretation - S.T., S.C.; Literature Review - S.C.; Writer - S.T., S.C.; Critical Review - Ö.A., Y.D.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

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