

# PEEK in dentistry, properties and application areas

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## Abstract

PEEK is a widely accepted material in medicine and dentistry. The aim of our study is to define and summarize the application areas of PEEK in dentistry. A retrospective literature research was conducted using the keywords ‘polyetheretherketone’, ‘PEEK’, ‘dentistry’, ‘dental’, ‘implant’, on the Pubmed and Google Scholar databases. The relevant articles were analyzed and summarized. In this review, the structure, properties and application areas of PEEK are explained. PEEK can be used in the biomedical field due to its excellent chemical and mechanical properties. Thanks to its bone-like elasticity modulus it can be used as an implant material, fixed and removable prostheses, obturators, pediatric dentistry, and orthodontics. In addition, PEEK is an alternative to metals due to its non-allergic and aesthetically acceptable properties. Nevertheless, improving PEEK's properties and increasing biocompatibility is a challenging process. It is expected that the use of PEEK in dentistry will increase due to the modifications applied.

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## Introduction

Polyetheretherketone (PEEK) is a polyaromatic compound which is a polyaryleterketone group (1). It is promising thanks to the appropriate physical and mechanical properties in the fields of medicine and dentistry.

There are many uses of PEEK: (2)

- maxillofacial and cranial implant,
- Spinal surgery,
- Orthopaedic surgery,
- A dental implant, root canal material carbon fiber reinforced PEEK(CFR-PEEK),
- Cardiac surgery

The areas of use in dentistry are (3-5):

- I. implants
  - a) implant
  - b) implant supported bar
  - c) abutment
  - d) temporary abutment
  - e) healing cap
- II. fixed prostheses
- III. endocrowns
- IV. removable dentures
- V. maxillofacial prostheses
- VI. orthodontic wire

PEEK is synthesized by an alkylation reaction that combines 4'40- difluoro benzophenone with hydroquinone salt Fig. 1 (6). Ether bond gives the

molecule an axial displacement, while the benzene ring gives stiffness.

The molecule has two microstructures: (6)

1. Crystalline phase
2. Amorphous phase (surrounds crystals)

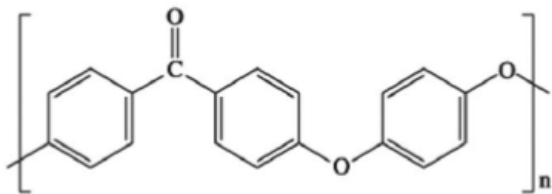


Figure 1. Chemical formula of PEEK

PEEK has a close modulus of elasticity to the bone (3-4GPa), it can be used as an alternative to metal implants (7, 8). PEEK is an inert material and its thermal properties remain stable in the human body (2). According to Katzer et al, PEEK and CFR-PEEK do not exhibit cytotoxic, mutagenic reaction (9). Similarly, PEEK does not show an allergic reaction according to the study of Wenz et al. (10). PEEK has high thermal degradation resistance, melting temperature is 334°C (2, 11). It provides radiolucent imaging, so it is compatible with imaging techniques such as magnetic resonance imaging (MRI), computerized tomography (CT), and X-RAY (12). Combination with barium sulfate can increase the radiopacity (6). It has resistance to gamma radiation (2). One of the disadvantages is unable to osseointegration (13)(14). This restricts its use on the implant surface or biomedically (15). Another disadvantage is that the bond strength is low during the veneering process with the composite since the wettability is insufficient (16). In addition, PEEK may be appropriate for individuals with metal allergies (17). It can also be reinforced with carbon or glass fibers and modified with nanoparticles (18). Carbon fiber-reinforced PEEK turns into black (6). Reinforced PEEK provides a more aesthetic appearance due to its white color on the gingiva, which has a fine biotype (19).

#### Advantages of PEEK: (6, 9, 20)

1. Resistant to radiation,
2. Resistant to various chemicals,
3. Insoluble in solvents in the mouth and at room temperature,
4. Stable over 300°C,
5. More durable than many metal restorations,
6. Can be reinforced with carbon fiber,
7. Tolerable in allergic patients,
8. Can be sterilized repeatedly without degradation

#### Disadvantages: (6, 21)

- Lack of osseointegration,
- Low wettability,
- Not aesthetic due to metallic gray,
- Difficult to manufacture implants,
- Radiolucent imaging.

### PEEK with Fixed Prosthesis

PEEK is a recommended material for fixed prostheses (16). PEEK has been modified by techniques such as mixing, filling, fiber reinforcement to obtain a material that is more rigid and suitable for dental use (12).

PEEK can be used in fixed prostheses because of its suitable mechanical properties thanks to inorganic chemicals in it (22). It can be produced by methods such as vacuum pressing, milling (Computer aided milling-computer aided manufacturing) (22). Also, PEEK is recommended as a framework material for a fixed dental prosthesis (23) due to its hardness (24). According to Lieberman et al. PEEK has low solubility and water absorption values when compared materials such as polymethylmethacrylate (PMMA) and can be considered for long term restorations (24).

PEEK is a white-gray non-aesthetic material and requires veneering for anterior use (16, 25).

Veneering methods are effective on fracture load. When digital veneering is performed, the fracture load is higher, regardless of the aging level (25).

Many studies have been done on strengthening the connection between PEEK and composite. Since conventional composite veneering applications were not sufficient for PEEK, different methods were applied. In studies with sulfuric acid and piranha solution, it has been observed that sulfuric acid increases the bond strength (16). Airborne-particle abrasion, etching and plasma treatment are known as methods to increase wettability (16).

According to the study by Uhrenbahr et al, airborne-particle abrasion (50µm alumina particles) and sulfuric acid etching (60 seconds) should be applied before bonding PEEK crowns. It was also concluded that retention was increased by the use of various bonding systems (Signum PEEK Bond, visio.link) (26).

According to the results on research conducted on the surface of PEEK, microwave supported coating technology can be used more quickly and reliably than conventional methods (15).

Load bearing capacity was evaluated in a laboratory study on a three-unit inlay retained bridge. The restorations with PEEK showed high load-bearing capacity and the fractures were mostly seen in the connector region (27).

Modified PEEK materials with ceramic fillers are preferred for temporary purposes in resin bonded fixed dental prosthesis(RBFD) since they are more aesthetic in appearance compared to metal

substructures (28). Similarly, veneered PEEK can be used as the interim framework of RBFDP in the anterior region as an alternative to materials such as metal-ceramic, glass infiltrated alumina, zirconia, and lithium disilicate (17).

## PEEK in Implants

Implant treatment is one of the most accepted indications in terms of success and satisfaction in treating missing teeth in today's dentistry.

PEEK was used in spinal and hip surgeries at the beginning and can now be used as computer designed craniofacial implants (29, 30). It can be used in the reconstruction of facial deformities with interlocking systems in jaw and zygoma deformities (31). In addition, the data of a review study shows that there are many positive properties compared to titanium alloys (32).

PEEK is a promising material that can be used as an implant with its low elasticity modulus (Young's modulus) and easily modified and strengthened carbon fiber-reinforced PEEK (CFR-PEEK)(5) and glass fiber-reinforced PEEK(GFR-PEEK) (33).

Since the osseointegration of PEEK is limited, osteoblast activity is tried to be increased by various surface modifications (13) Surface properties and chemistry, increasing wettability are decisive for cell adhesion and proliferation (14). A number of studies have been carried out to improve the wettability of the material by changing the surface properties. Alumina-coated PEEK samples were examined by Akkan et al. with oxygen plasma etching and laser modification, according to the data obtained, wettability is increased for implantation (14). PEEK is coated with hydroxyapatite and promising results were obtained (21).

Plasma immersion ion implantation (PIII) technique can be applied by using water-H<sub>2</sub>O and ammonia-NH<sub>3</sub> to improve the bone interface properties of PEEK implants. With this application, effects on cell interaction, surface adhesion, proliferation, osteogenic differentiation have been increased (34).

CFR-PEEK, pure PEEK and titanium implants were compared using finite element analysis. In this study, stress, deformation, and contact pressures were investigated by applying force on these implant materials with 100 N parallel and 30° angle from the buccal surface. Accordingly, CFR-PEEK implants achieved almost the same values as titanium, but more work was needed for pure PEEK (35).

The internal spline mechanism has been developed as an alternative to the hexagonal mechanism commonly used in the implant abutment interface. In order to measure the average insertion torque and the suitability for immediate loading, a 32 N cm torque was applied to titanium, PEEK and CFR-PEEK dental implants. Titanium implants were found to be more resistant in this study (36).

Several methods have been developed to alter the surface properties of PEEK to improve bioactivity (33).

The change in surface properties after sandblasting with aluminum oxide was investigated. Reinforced (CFR-PEEK) and filler (ceramic filled PEEK) were found to be suitable surface roughness for osseointegration after blasting (37). PEEK surface development processes are summarized in Table 1 (7).

According to Khonsari et al, although PEEK is a promising material in dentistry and implantology, there are cases with failure when used as an implant. Therefore, further research is needed (40).

Histological examinations revealed different tissue behavior and inflammatory cytokines around different implant materials. The level of DNA is less pronounced around PEEK implants, with alkaline phosphatase and osteocalcin levels are higher around Titanium-Aluminum-Vanadium alloys. However, IL1-β, IL-6, IL-8 levels, which are proinflammatory cytokines, have been observed higher around PEEK implants and at least around Ti alloys. Antiinflammatory cytokine IL -10 level was higher in Ti alloys than PEEK. The cause of fibrosis tissue formation around PEEK implants can be attributed to the formation of these proinflammatory cytokines. However, Ti alloy surfaces provide a more favorable environment for osteogenic activity (41).

Various materials are used in as implant abutments, such as titanium, gold, zirconia, alumina, and glass. High-strength polymer materials such as PEEK are also recommended as abutments in many implant-supported restorations (18). Less bacterial biofilms are observed compared to titanium and zircon abutments. Research has shown that PEEK can be used as an immediate definitive abutment and framework material (18).

A study conducted by Kaleli et al. noted that the use of custom PEEK abutments increases stress and is not suitable for posterior use in individuals with parafunctional habits (42).

According to Neumann et al. when used as an abutment, PEEK exhibits lower fracture resistance than titanium alloys (43). It was concluded that reinforced PEEK abutments are a good alternative to titanium abutments in an animal study evaluating the effect of PEEK and titanium abutments on biological width and soft tissue stability (19). Similarly, in an animal study that examined the effect of pure PEEK, roughened PEEK, titanium bonded PEEK and titanium healing abutments on hard and soft tissue healing, it was concluded that PEEK healing abutments were an alternative to titanium (44).

In the all-on-four treatment protocol, PEEK framework can be used in the production of implant-supported fixed prostheses during the permanent loading. According to Zoidis, when PEEK is produced by veneering with PMMA, considering the aesthetic and biomechanical advantages of PEEK, it's been a good alternative to conventional ceramic and metal-ceramic prostheses (45).

In a study comparing tensile strength between PEEK and Titanium abutment screws, titanium screws were found to be significantly resistant. However, PEEK reinforced by > 50% continuous carbon fibers can be considered as abutment screw (46).

In 10 patients with maxilla anterior defect, fixed acrylic restoration study was performed using PEEK and titanium subperiosteal implants. PEEK implants

produced by CAD-CAM have positive results despite limited osseointegration properties (47).

**Table 1.** Surface treatment of PEEK

Coating	<ul style="list-style-type: none"> <li>• Plasma spraying- hydroxyapatite (21)/ titanium</li> <li>• Spin coating</li> <li>• Electron beam evaporation (EBE)</li> <li>• Plasma immersion ion implantation (PIII)</li> </ul>
Surface topographical modification	<ul style="list-style-type: none"> <li>• Acid etching -Sulfuric acid(38, 39) - Piranha acid(26)</li> <li>• Sandblasting - TiO<sub>2</sub>, Aluminum oxide (37)</li> </ul>
Chemical modifications	<ul style="list-style-type: none"> <li>• Sulphonation</li> <li>• Amination</li> <li>• Nitration</li> </ul>
Incorporating with bioactive properties	<ul style="list-style-type: none"> <li>• Bioactive inorganic materials</li> </ul>
Improving hydrophilicity	<ul style="list-style-type: none"> <li>• UV irradiation</li> <li>• Plasma gas treatment</li> </ul>

## PEEK with Removable Prosthesis

In the indications of removable prostheses, intraoral examination, patient's expectations, and material selection are important. Removable partial dentures are supported by the mucosa or teeth. PMMA based acrylics are used as base material and Cr-Co alloys are preferred for the framework. However, it causes aesthetic and allergic problems. Polyamides (deflex, valplast), developed for a solution, are produced by thermal injection, have more aesthetic and nonallergic compounds. Removable dentures should have rigid major connector components but polyamide materials show weakness (48-52). In addition, polyamides are less preferred because of their color instability, difficulty in repairing, bacterial and fungal colonization (51). However, acetal resins are also seen as flexible, aesthetic base and clasp material (53). In the study that investigating removable partial dentures' fit to tissue and teeth produced by PEEK, the gap between occlusal rest, major connector and denture base was measured. It was observed that PEEK RPDs produced by CAD-CAM technology was more compatible than conventional Cr-Co RPDs (54). Modified PEEK (BioHPP) is a material that can be an alternative to conventional RPDs considering the positive properties. Low plaque affinity, nonallergic, water insolubility, hygienic, easily relined, lower weights are advantages of modified PEEK. Also, it can be produced by CAD-CAM or conventional lost wax techniques (55). Also according to Arnold et al. by using CAD-CAM techniques RPD frameworks can be produced more compatible than the casting technique (56). In addition, vertical dimension

arrangement can be made with temporary RPDs using digitally fabricated PEEK frameworks (57).

Another area may also be the construction of obturator prostheses. Due to the light weight of PEEK, it is possible to rehabilitate large oronasal defects (58).

## PEEK in Orthodontics and Pediatric Dentistry

PEEK can be used in orthodontics and pediatric dentistry. It can be designed and applied as a space maintainer digitally. The aim here is to improve the quality of treatment. Also, PEEK is promising as an orthodontic appliance (59). For a solution of nonmetallic wire in orthodontics, PEEK arc wires have been developed. PEEK is considered as a nonmetal and aesthetic arc wire due to its properties such as high bending strength, creep resistance, similar orthodontic force to Ni-Ti wire and low water absorption (60). In the PEEK tube method developed by Shirakawa et al, the metal arch wire was passed through the PEEK tube and acceptable aesthetic appearance was obtained (61). PEEK wires can be applied as an alternative to Ni-Ti (62).

## Conclusions

PEEK is a highly durable polymer which has good mechanical and physical properties and has been used in many fields in recent years. With the introduction of PEEK in dentistry, progress has been made. PEEK used in prosthodontics as an implant



material, abutment, fixed, removable partial prosthesis frameworks. Several studies have been conducted in vitro to increase the binding potency with resins. It is also accepted as an alternative to space maintainers and Ni-Ti wires in orthodontics. Based on its positive characteristics, PEEK is a promising material in dentistry and industry.

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