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Clinical applications and improvement of resin bonding for PEEK in resin-bonded fixed dental prosthesis: A review

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Abstract

Resin-bonded fixed dental prostheses (RBFDPs) are a commonly used precision treatment, such as fixed dental prosthesis (FDP) and implant-supported dentures. Full crown preparation of vital teeth, which is required for traditional FDPs, may result in a risk of pulp reaction as a large portion of the coronal tooth structure must be removed. RBFDP has been recognized as a non-invasive or minimally invasive treatment modality for the replacement of single missing teeth. RBFDPs require much less tooth preparation than conventional FDPs.
These dental treatments are restorative solutions used to cover missing teeth and achieve an aesthetic smile. The biomechanical rules, aesthetics, polishability, and bond strength have been emphasized in RBFDP treatments.
Polyetheretherketone (PEEK) is one of the most widely used biomaterials in dentistry. The material, which stands out especially with its acceptable aesthetics, biocompatibility and modulus of elasticity close to dentin, has enabled it to be used in RBFDP treatments. Since PEEK is lighter than metal alloys, patients experience less discomfort and a feeling closer to natural teeth. Furthermore, the thermoplastic properties of PEEK are claimed to provide a precise fit, allowing the restoration to better integrate into the natural tooth structure. In addition, its ability to be customized using different modern manufacturing techniques is thought to offer dentists and patients a reliable option for successful long-term treatment.
Our review is about the use of PEEK material as an alternative material in RBFDPs with low negative effects on periodontal tissues and their bonding with resins.

Keywords: Fixed dental prostheses, PEEK, Polyetheretherketone, polymer, resin-bonded

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Introduction

RBFDPs represent an alternative treatment, especially for eliminating aesthetic deficiencies in the anterior region. These prostheses allow conservative rehabilitation by protecting abutment teeth and periodontal tissues (1, 2).

RBFDPs have been used for many years with high success rates. In addition to overcoming aesthetic concerns, these prostheses are also very successful as inlay-retained fixed dental prostheses in the posterior region if they are made with appropriate design and materials. In addition, RBFDPs have a number of advantages, such as low cost and minimally invasive preparation of teeth. The survival and aesthetic success rates of RBFDPs can be increased by considering specific criteria, especially in young patients (3). It is important that RBFDPs are an alternative treatment option because they cause less tissue loss compared to fixed dental prostheses (2). Success is enhanced by an ideal occlusion, optimum material thickness, the position of the abutment teeth, and the maintenance of periodontal health (4). However, improved survival is mostly possible with the high bond strength between the prosthesis and the teeth. Therefore, resin cements and dentin bonding agents have a crucial role in treatment (5).

Different materials for adhesive prostheses have been investigated for many years. In these treatments, single materials such as all-ceramics or combined materials such as metal-based porcelains are usually used in RBFDPs (5). Metal-supported RBFDPs show good long-term survival. The disadvantage of these materials is that they exhibit high debonding rates. In addition, they show gray color reflections due to insufficient translucency (6).

All-ceramic restorations such as feldspathic porcelain and glass-infiltrated alumina were introduced as an alternative treatment option to overcome the aesthetic problems caused by the presence of metal, especially in areas with aesthetic demands. In addition, clinical studies have reported that all-ceramics show a high fracture rate in the proximal connector between the tooth abutment and the pontic (6). Zirconia has been widely used in RBFDPs due to its high compressive strength. However, debonding failure can be encountered in the short and long terms. Researchers aimed to achieve high bond strength by using bonding agents to avoid this complication (5).

The difference in modulus of elasticity between the abutment teeth and the prosthesis during function causes stress concentration at the cement interface. It has been underscored that these stresses are the main cause of RBFDP debonding (6, 7). Long edentulous spans increase the rate of this failure (8). In previous studies, alternative materials such as fiber-reinforced composite (FRC), polymethyl methacrylate (PMMA), and PEEK have been presented for RBFDPs (1, 2, 6, 9).

The purpose of this review is to provide detailed information about PEEK material as an alternative material in RBFDPs.

Why is PEEK an alternative material in RBFDPs?

PEEK is a thermoplastic and synthetic, tooth colored polymeric material with high mechanical properties. The use of PEEK has become increasingly common in medical and dental treatments (10). The monomer unit of etheretherketone monomer polymerizes by a step-growth dialkylation reaction of bis-phenolates to produce polyetheretherketone (Fig. 1) (10). The material has high thermal resistance, chemical stability, and biocompatibility. One of the most important reasons for the increasing popularity of PEEK is that it has a low modulus of elasticity (Young's Modulus: 3-4 GPa, Tensile Strength: 80 MPa), closer to the dentin and alveolar bone compared to many routinely used prosthetic and restorative materials (6). It has been argued that the low modulus of elasticity reduces the stress at the cement interface and thus reduces the risk of complications. PEEK frameworks are also lighter than metal frameworks. As a result, patient satisfaction and comfort during the function are increased (11).

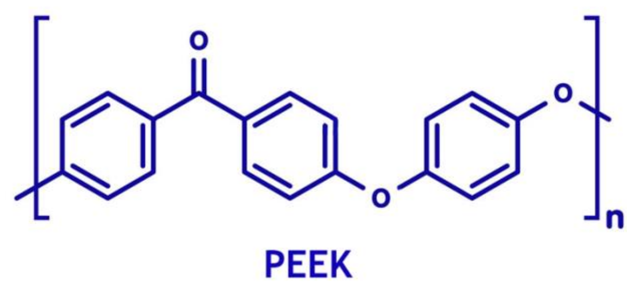

Figure 1. Chemical structure of monomer unit of PEEK.

PEEK has a lower wear rate than metal alloys. Its low density (1.31 g/cm^3) allows for the fabrication of lightweight restorations and ideal stress distribution (12). In the treatment of edentulism with PEEK FDPs, PEEK provides stress absorption for the abutment teeth and, thereby, protects them against fracture when the occlusal force load is at the pontic. The mechanism underlying this protection is that PEEK absorbs fracture energy via elastic deformation before rupture (13).

Previous studies on PEEK reported that it can be considered a viable alternative material for FPDs and provides satisfactory clinical results (14). PEEK can be easily fabricated for prosthetic treatments using computer-aided design/computer-aided manufacturing (CAD-CAM), 3D printers, and lost wax techniques (15). In dentistry, 3D printed materials can be manufactured with minimum time, material, and cost using additive manufacturing (AM). Lightweight PEEK dental products constructed with AM improve patient comfort and satisfaction (16).

Although PEEK has a low modulus of elasticity, it exhibits excellent mechanical properties and low water solubility. For these reasons, PEEK is considered a suitable material for use in dental practice, including long-term restorations (17).

In order to increase the success of prosthetic treatment, factors affecting the health of soft tissues need to be considered. These are plaque accumulation and bacterial adhesion caused by rough surfaces. Therefore, the correct selection of materials coming into close contact with the gingiva is indispensable for long-term dental rehabilitation (18).

PEEK displays better wear resistance than zirconia ceramics and metal alloys and is less abrasive to the antagonist tooth (19, 20). Due to its low radiopacity, PEEK provides clinically better performance than zirconia and metal alloys. With the PEEK material, it is particularly easy to control the margin areas and detect carious lesions (21). Precise margins are integral to successful crown restorations, and failures may result in adhesive dissolution, dentin hypersensitivity, periodontitis, and secondary caries. Compared to crowns with zirconia coping, crowns with PEEK coping were shown to have better internal adaptation and margin fit. In a study comparing manufacturing techniques, pressed PEEK showed a larger marginal gap than CAD-CAM-milled PEEK. However, both were within the clinically acceptable limits (22). It was reported that PEEK displays a lower marginal gap and higher fracture resistance when compared with PMMA and polylactic acid for short-term use in prosthetic treatments (23).

Regarding the clinical utility of PEEK for FPDs, Rauch et al. stated that PEEK offers the advantages of requiring less manufacturing time and being lighter than zirconia ceramics. It was also noted that when the veneering resin is applied, PEEK provides aesthetically acceptable results that are comparable to those achieved with zirconia (21).

PEEK can be polished using laboratory and chairside protocols. High wear resistance and low plaque affinity of PEEK are important for periodontal health (6, 24). PEEK can achieve acceptable surface topography and low roughness values with different polishing protocols (25-27). Nevertheless, it should be kept in mind that artificial aging increases the surface roughness of PEEK (28).

One of the advantages of using PEEK as an alternative material is that it can be easily bonded with resin cements for definitive cementation (29, 30). Resin cement is used for tooth and prosthetic material bonding in RBFDPs. The high resin cement bond strength of the PEEK material makes it superior in terms of debonding problems (1, 6). PEEK has poor aesthetic properties. This material can be veneered with indirect resin composites. Thus, a more natural appearance is obtained with veneering (29, 31, 32).

PEEK has a grayish-brown or white opaque color and needs to be veneered with a resin composite for aesthetic concerns. Various surface pretreatments have been proposed to improve the bonding of PEEK to resin composites (12). PEEK has an inert and hydrophobic surface, and this makes it difficult to use it in combination with other materials without pretreatment (33). One of the major drawbacks of the PEEK material is its low wettability. This problem can negatively affect the bonding of resin materials. Increasing the surface roughness by abrasion reduces this problem by increasing the surface area. The rationale behind increasing the surface area is to increase the infiltration of the resin to the surface (34). Increasing surface energy and wettability reduces surface tension (35). Surface treatments such as sandblasting, acid etching, plasma spray, and laser etching are used on the surface of PEEK to enhance wettability (10). In addition, surface coating methods have also been attempted to increase the surface energy of PEEK (36).

Metal frameworks are frequently used as material for RBFDPs. These materials may corrode when they come into contact with oral liquids. Metals can cause allergic reactions (37). Metallic taste as a result of reactivation of metals is also a disadvantage for metal-containing RBFDPs (38). The use of PEEK as a prosthetic material is not associated with such problems (10, 39)

If a chipping occurs during the use of PEEK materials after veneering, chairside repair can be easily performed intraorally without debonding. Compared to all-ceramic and metal-supported ceramics, PEEK can be repaired quickly and easily with resin composites intraorally. It is also important that optimal aesthetics and ideal soft tissue profile can be achieved with PEEK RBFDPs. The authors reported that preparations can be easily made using tungsten carbide burs intraorally (6).

Different composites can be obtained by modifying PEEK with various reinforcing materials. Being a synthetic polymer, PEEK allows the production of modified chemical configurations. In this way, the elastic modulus of the material can be modified. Higher levels of wear resistance, elastic modulus, and mechanical properties can be achieved by modifications of PEEK (40).

PEEK can be modified with glass fibers (12 GPa) or carbon fibers (18 GPa). As a result, PEEK exhibits an elastic modulus that is even closer to that of human bone and dentin, greater flexural strength (170 MPa), and better color stability (14).

Studies and clinical reports on the use of PEEK in RBFDPs are limited. In a case report presented by Zoidis et al. researchers preferred PEEK RBFDP as a temporary prosthesis for the aesthetic rehabilitation of the patient during the osseointegration period after implantation. PEEK framework (BioHPP®, Bredent GmbH, Senden, Germany) was fabricated using the lost wax technique. The authors stated that retentive grooves or occlusal/cingulum rests were used to address the debonding problem of metal-supported RBFDP. They emphasized that less pre-prosthetic preparation time is required for PEEK frameworks, and therefore, minimally invasive procedures provide an advantage compared to metal frameworks. The authors noted superior resin bond strength between the abutment teeth and the PEEK material in RBFDP compared to metals. For veneering on the framework, 110 µm alumina powder was roughened under pressure in order to increase the resin composite bonding. This way, a larger bonding surface area was obtained. The bond strength of the materials is increased with the adhesive agent (Visio.link®, Bredent GmbH, Senden, Germany). An indirect light-polymerized resin composite material was used as the veneer material. Finally, dual-cure resin cement was used for the cementation of RBFDP. No complications were reported during the 4-month follow-up of the patient during the osseointegration period (6).

In a similar publication, a case report of a 14-year-old patient with a missing maxillary lateral tooth was presented, in which a veneered PEEK RBFDP was applied for temporary use until implantation. PEEK frameworks (BioHPP) were fabricated using the lost wax technique. Cementation was performed with an adhesive agent and resin cement after sandblasting. The authors argued that PEEK RBFDP is a good alternative to removable appliances in terms of stability and patient satisfaction. It has been stated that connector failure can be prevented compared to the all-ceramic RBFDP. In addition, similar aesthetic outcomes were obtained with veneering. PEEK and resin composites have low elastic modulus compared to metals and ceramics. Therefore, they claimed that the debonding rate would decrease (1).

In a recent clinical report, missing bilateral mandibular first molars were treated with PEEK inlay-retained RBFDPs. The authors reported that PEEK frameworks could potentially offer long-term high survival rates. Careful patient selection, proper tooth preparation, strict cementation protocols, and customized framework design have been demonstrated to prevent complications of the prosthesis during function (9).

Cekic-Nagas et al. presented an experimental study on the use of CAD-CAM-milled PEEK frameworks (PEEK Techno Med®, ZirkonZahn, Bruneck, Italy) as inlay-retained RBFDPs in the posterior region. In the study, the load-bearing capacity of different materials was investigated. The PEEK material was compared with routinely used resin composites, FRC, and PMMA. According to the findings of the study, the PEEK inlay-retained RBFDP showed superior load-bearing capacity. It has been shown that all the losses in the PEEK group occurred at the connectors. The PEEK group exhibited a load-bearing capacity of up to approximately 1000 Newtons. It was concluded that the PEEK material can be used as a long-term inlay-retained RBFDP in the posterior region (2).

Enhancement of PEEK-Resin bonding to improve survival of PEEK RBFDP

Several techniques and surface treatments have been studied to improve the bonding of PEEK with resins. Studies have shown that no bonding occurs between the PEEK surface and resin materials without surface pretreatments. Increasing the surface area of the material by surface roughening and reducing the hydrophobicity have been proposed to achieve durable bonding (29).

Among the surface modification methods used for PEEK, sandblasting is a convenient abrasive method that provides a high bond strength (41). Various sizes of alumina (Al_2O_3) particles are used for sandblasting (42-45). Coating methods are both simple and cost-effective surface treatments. Another coating method used in dentistry is the tribochemical silica method, which is based on abrasion with airborne particles. Using this method, the PEEK surface can be coated with silica. Silica coating with Cojet® (30 µm silica particles; 3M ESPE, Seefeld, Germany) and Rocatec® (110 µm, 3M ESPE, St. Paul, MN, USA) is used in dental laboratories, with successful outcomes (46).

Hydrolysis takes place between the ether and ketone bonds of the material during acid treatment (31). 98% H_2SO_4 was shown to provide adequate bonding between the PEEK surface and resin (47). According to Schmidlin et al. H_2SO_4 interacts with carbonyl and ether groups of PEEK. Piranha solution, on the other hand, exerts its effect by increasing surface polarity and aromatic ring opening after oxidizing PEEK. Thus, auxiliary functional groups are obtained for bonding (29).

Mixed results were reported by studies examining the effect of laser treatment on the bond strength of PEEK to resin materials. Combined use of Er:YAG laser treatment with sandblasting and silica coating was found to produce successful and durable outcomes; however, when used alone, Er:YAG laser irradiation failed to achieve the desired results (48). In a study by Tsuka et al. greater shear bond strength was demonstrated in samples with grooves at different depths (100 µm, 150 µm, 200 µm) on PEEK surfaces treated with Nd:YVO4 (Neodymium-doped yttrium orthovanadate) laser compared to samples with no surface treatment or sandblasted samples but the difference was non-significant (49).

Plasma treatment is safer than chemical abrasion methods since it only modifies the chemical and physical characteristics of the PEEK surface within a thin layer. In plasma application, the depth of penetration can be increased, resulting in improved bonding performance (14). Correspondingly, studies have been conducted aiming to improve bonding with resin cements by increasing the surface energy and wettability of PEEK with plasma treatment (42, 50-52).

Conclusion

Further experimental studies on the use of PEEK in RBFDPs are warranted. Clinical studies are generally limited to short-term case reports. It should be kept in mind that, in addition to the prosthetic design and prosthetic material used, good oral hygiene and dental care are essential for the longevity of dental prostheses. PEEK RBFDPs represent a promising treatment option. Long-term clinical follow-up and experimental studies are needed in terms of survival and periodontal health.

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