

Use of novel polyetheretherketone (PEEK) polymer in pediatric dentistry

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Received: 12 June 2025

Accepted: 18 July 2025

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How to cite this article:

Akgün SE, Yıldız Ş, Tekin S. Use of novel polyetheretherketone (PEEK) polymer in pediatric dentistry. Int Dent Res. 2025;15(2):85-91.
<https://doi.org/10.5577/intdentres.486>

Abstract

The purpose of this study is to discuss the applications of PEEK in pediatric dentistry and the advantages of PEEK material in terms of periodontal health. In pediatric dentistry, there is a continuous search for biocompatible, esthetic, and durable materials to overcome the limitations of conventional options such as stainless steel and zirconia. Polyetheretherketone (PEEK), a high-performance semicrystalline polymer, has emerged as a novel alternative due to its superior mechanical properties, resistance to heat and chemicals, and an elastic modulus comparable to human bone. This review aims to evaluate the material characteristics of PEEK, its impact on periodontal health, and its clinical applications within pediatric dentistry. PEEK is amenable to digitalization and can be fabricated using CAD/CAM milling and 3D printing, ensuring precise fit and patient comfort. In pediatric orthodontics and space maintenance, PEEK serves as an esthetic, metal-free alternative, eliminating risks of nickel allergy while providing high strength and significantly reduced weight compared to traditional appliances. For restorative procedures, PEEK is utilized in crowns, endocrowns, and post-core systems. Its shock-absorbing capability allows for favorable stress distribution in dentin, reducing the risk of root fractures often associated with rigid materials like metal or glass fibers. Additionally, its low specific gravity and biocompatibility make it an effective material for obturators in treating cleft lip and palate defects. Regarding periodontal health, polished PEEK surfaces demonstrate low plaque affinity and acceptable surface roughness, supporting gingival health. PEEK offers distinct advantages in pediatric dentistry, particularly for patients requiring metal-free, lightweight, and shock-absorbing restorations. While it presents a promising alternative to traditional materials, achieving durable adhesion requires specific surface treatments, and further prospective clinical studies are warranted to validate its long-term performance.

Keywords: PEEK, pediatric dentistry, space maintainers, biocompatibility, CAD/CAM, periodontal health, dental application

1. Introduction

In dentistry, there is a constant search for ideal techniques and new materials with improved properties (1). However, for many applications, no single material is available that can address all the challenges faced by dental practitioners (2, 3). For a novel material to be incorporated into advanced dental applications, it must demonstrate biocompatibility, low plaque affinity, good esthetic features, and mechanical properties that are similar to those of dentin, enamel, and bone structures. Recently, the PEEK material has been developed to meet these requirements, offering superior biomechanical properties, good tolerance by living tissues as opposed to metallic materials, and improved esthetics (4).

PEEK is a high-performance engineering plastic. PEEK is used in demanding applications in many industries, including aerospace, automotive, electronics, and medical technology, owing to its superior mechanical properties, such as high resistance to heat, wear, and fatigue, and excellent electrical insulation (5-7). As demonstrated by in vitro studies, PEEK is a biocompatible and inert material, and none of its components are associated with cytotoxic, mutagenic, carcinogenic, or immunogenic effects (3, 8, 9). In some studies, PEEK composites with a porous scaffold structure impregnated with bioactive materials have been designed to improve the biological activity of PEEK (10-13). Moreover, PEEK has good dimensional stability and an elastic modulus between that of the cortical and cancellous bones (14).

PEEK has several applications in dental practice due to its extraordinary mechanical properties, low elastic modulus compared to metals, suitability for use in individuals with an allergy to metals, and good esthetic outcomes (1, 3, 15). The areas of PEEK use include dental implants, fixed and removable prostheses, maxillofacial prostheses, orthodontic wires, and space maintainers (1, 3, 16, 17).

2. Clinical and research consequences

2.1. The behavior of PEEK material on periodontal tissues

PEEK material can be used as an implant, abutment, and healing abutment in dental implantology because of its non-allergenicity and biocompatibility, and in cases where sinus perforations are avoided. The wear properties and plaque accumulation levels of dental materials are also important for periodontal tissue health. In addition, the surface roughness of dental materials affects their esthetic properties and wear resistance. Surface roughness significantly affects the plaque affinity of dental materials. A dental prosthesis with a Ra value below 0.2 μm is considered to have an acceptable surface roughness in terms of microbial plaque adhesion (18, 19). PEEK was found to have a higher nano surface roughness than processed titanium (20). In a study by Benli et al., pure PEEK displayed a

lower Ra value compared to polymethyl methacrylate (PMMA), after wet polishing using 2500- and 4000-grit silicon carbide paper (21). In a similar study, high-performance polymers with different compositions fabricated using CAD/CAM exhibited comparable surface roughness. Pure PEEK, modified PEEK materials, and fiber-reinforced resin composites have clinically acceptable surface roughness (22).

Kurahashi et al. found clinically acceptable Ra values after examining the effect of various polishing protocols on the surface roughness of PEEK (23). In another study, when biofilm formation on polished PEEK and sandblasted PEEK was compared, greater surface roughness and increased bacterial count were observed on sandblasted PEEK (24).

Hahnel et al. evaluated biofilm formation on different materials (zirconia, titanium, PMMA, and PEEK) and observed lower or equal biofilm formation on PEEK and PMMA surfaces than on zirconia and titanium surfaces. The surface of PEEK is smoother than that of zirconia and titanium (25). However, in a separate study comparing the surface roughness of polished PEEK with that of pure titanium (Cp-Ti) and titanium-6 aluminium-4 vanadium (Ti6Al4V- α +B titanium alloy composed of 6% aluminum and 4% vanadium), PEEK surfaces exhibited greater roughness than Cp-Ti and Ti6Al4V surfaces. Increased adhesion of *Streptococcus sanguinis* was observed on PEEK surfaces compared to Ti6Al4V surfaces (24).

2.2. Production methods of PEEK material

The characteristics and applications of PEEK in dental practice have been investigated in many studies (26,27). PEEK can be fabricated using the vacuum heat-pressing and lost-wax technique as well as CAD/CAM milling and 3D printing (28). Recently, removable PEEK prostheses have been fabricated using 3D printers. This type of additive manufacturing allows for complex designs (29). Obturators manufactured using a 3D printed PEEK framework have also been observed to fit well with oral tissues. However, few studies have reported on the long-term performance of 3D-printed PEEK materials (30).

Digital impressions obtained by using intraoral scanners improve patient comfort by preventing gag reflexes. CAD/CAM systems enable the fabrication of more precise dental restorations by eliminating labor-intensive work and human errors. In addition to the aforementioned advantages, CAD/CAM systems provide rapid, effective, and comfortable restorative solutions and are considered an alternative to conventional techniques. Intraoral scans offer a stress-free experience, especially for uncooperative children, by allowing breaks during the procedure and not requiring rubber dam isolation while taking impressions. Considering the high interest of today's children in digital devices, displaying the intraoral procedures on a screen during scanning will improve child's cooperation (31, 32).

In pediatric dentistry, the choice of treatment should be based on the individual needs for restorative materials. Treatment decisions should be made taking into account the inherent advantages and shortcomings of each material (1).

The novel PEEK material is fabricated using CAD/CAM systems and 3D printers.

3. The use of PEEK material in pediatric dentistry

3.1. Space maintainers

In children, the preservation of deciduous teeth in the mouth until they fall off on their own is important for oral treatment planning (33, 34). Conventional removable and fixed space maintainers (SMs) have been used in dentistry for many years (35). Researchers found that children using traditional space maintainers have increased periodontal index scores and greater bacterial accumulation in the oral cavity (36, 37). In addition, higher nickel sensitivity has been reported in children using intraoral appliances containing nickel, an allergen (38).

In a study comparing intraoral nickel release from space maintainers and stainless-steel crown (SSC) restorations, greater nickel release was found for space maintainers (39). It has also been reported that conventional removable space maintainers exhibit shrinkage and microcrack formation over time (40).

Researchers have suggested using an alternative stainless steel alloy or covering it with a biocompatible substance to avoid potential health risks in children. With the help of CAD/CAM or 3-dimensional (3D) printing technology, digital space maintainers ('digitainer') can be fabricated using more innovative and biocompatible materials, possibly with fewer drawbacks than traditional space maintainers. Since the PEEK material is metal-free, space maintainers made of PEEK can be used in patients who are allergic to metals or dislike the metallic taste owing to its natural tooth-color appearance and favorable esthetics (40).

Ilerardo et al. reported that after a 9-month follow-up, patients were extremely satisfied with the lingual and palatal arch space maintainers made of CAD-CAM PEEK material (40). Likewise, Kun et al. reported that fixed bilateral space maintainers made of PEEK are 75% lighter than their conventional counterparts (41).

In a study by Guo et al., who compared digital removable pediatric space maintainers (SMs) made of PEEK with those manufactured using traditional methods, the digitally fabricated SMs exhibited a better fit on the plaster model. In addition, the conventional fabrication of SMs requires multiple steps and extensive polishing. Therefore, the authors concluded that digital technology is more feasible than conventional methods for producing removable SMs (42).

In an in vitro study, Tokuç et al. reported no difference in the band fit of metallic band-loop SMs made

of PEEK material (digital) and SMs fabricated using conventional methods. CAD/CAM technology is increasingly used in pediatric dentistry. The authors noted that a comparison of conventional SMs with digital SMs in terms of fracture resistance, patient comfort and preference, and clinical success in future studies is warranted (32).

Soni stated that CAD-CAM-fabricated ceramic SMs may be a good alternative to traditional band-loop space maintainers. The new ceramic appliance offered advanced esthetics and was well tolerated by the pediatric patient. However, it was noted that, since this material is the first of its kind, further clinical research is needed to confirm the success of the new SM over time (43). We believe that CAD-CAM-milled PEEK may also serve as an alternative SM material.

Furthermore, for use in space maintainers, the dull appearance of the PEEK material can be addressed by the addition of whitening agents (42). Pure PEEK material has a brownish or gray color, which limits its clinical applications. In previous studies, titanium dioxide and ceramic particles have been added to the substrate to obtain appropriate tooth colors. However, the colors obtained to date are still limited as compared to dental shade guidelines. It has been recommended that PEEK be veneered with resin composite to mimic vivid enamel shades. Further research is required to provide more color options for PEEK (28).

3.2. Pediatric orthodontics

PEEK has been considered for use in orthodontics because of its advanced esthetic features, which make it suitable for patients who prefer metal-free appliances. The acceptable chemical and physical characteristics, biocompatibility, low plaque affinity, and dimensional stability of PEEK account for its increasing use in dentistry (40, 44).

PEEK is regarded as a metal-free, esthetic archwire because of its high bending strength, ability to produce orthodontic forces similar to nickel-titanium (NiTi) wires, and low water absorption (45).

Compared to orthodontic wires made of traditional polymers, such as polyethylene sulfone (PES) and polyvinyl difluoride (PVDF), PEEK wires offer greater orthodontic strength. In addition, PEEK can be used as an alternative to Ni-Ti and titanium-molybdenum (Ti-Mo) because it provides similar orthodontic forces (45,46).

In a study by Kadhum and Alhuwaizi comparing the performance of 0.8 mm round PEEK wires to conventional retainers bonded with 4 mm composites in terms of debonding and pull-out forces, the PEEK wires showed a performance similar to that of conventional retainers (47). In line with the aforementioned data, we think that PEEK wires can be used as splint wires in children after dental trauma.

The PEEK material is radiolucent and therefore not associated with artifacts on panoramic radiography obtained during orthodontic treatment (48).

There is an increasing demand in modern orthodontics for non-metallic products. With the widespread use of digital technologies, the PEEK material seems promising for the design of custom-made orthodontic wires (44).

3.3. Use of PEEK for tooth restoration

The prevalence of caries in primary dentition is quite high across the world (49). Stainless-steel crowns (SSCs) have been recommended for the restoration of multisurface lesions to achieve long-term success (50, 51). Although SSCs have high success rates, they have poor esthetics compared to other restorations. Prefabricated zirconia crowns have overcome esthetic concerns. However, their clinical use is limited by the requirement for an extended preparation phase, resulting in excessive gingival bleeding, as well as its rigid, non-flexible nature, and high cost (50, 52, 53).

PEEK serves as a cushion against occlusal forces owing to its low elastic modulus (3.0-5.5 GPa)(28).

Teng et al. reported that, through a combination of polydopamine (PDA) coating and plasma pretreatment, the bonding of the PEEK material could be improved. They noted that PEEK might represent a potential option and an alternative to ceramic crowns for restoring primary dentition in the future (52).

Because PEEK has a dull appearance with a white-to-gray color, it fails to meet aesthetic expectations. Therefore, PEEK restorations need to be covered with esthetic materials, such as veneering resins. The fracture load of a PEEK framework without veneering was reported to be 1385 N. This corresponds to approximately 2.5 times the average bite force in the posterior region (54).

PEEK is naturally radiolucent and can be used with imaging techniques such as computed tomography (CT), magnetic resonance imaging (MRI), and X-ray imaging. The radiolucency of PEEK allows for the examination, diagnosis, and treatment of clinical dental diseases without the need to remove or modify the framework (16).

One of the major advantages of PEEK is its ability to bond with indirect light-cured composites. To meet esthetic requirements, this material with low translucency can be coated with resin composites. In addition, Zorba et al. reported that the conventional coating method failed to achieve optimal bonding between PEEK and resin composites. In their study which evaluated the effects of various surface conditioning and curing techniques on shear bond strength of direct and indirect composite materials, higher shear bond strength was found after sulfuric acid treatment, etching with alumina particles, and plasma treatment (55).

Effective bonding is a prerequisite for using the PEEK material as a prefabricated crown. However, it is difficult to obtain strong and durable adhesion with dental materials because of their inherent properties, such as surface hydrophobicity, low surface energy, and chemically inert surfaces. Thus, a number of studies have

addressed these concerns using different surface treatment methods. Studies have shown that adequate bonding cannot be achieved when the PEEK polymer is veneered without any surface modification (52).

With the help of resin systems, good adhesion of the PEEK material to the tooth can be obtained. Therefore, it has been suggested that PEEK can be a successful alternative for inlay, onlay, endocrown, and post-core restorations in teeth with severely damaged crowns (56).

Although the use of inlay, onlay, endocrown, and post-core restorations is uncommon in children, they can be preferred especially for teeth with extensive coronal destruction. In a study by Tekin et al. evaluating the use of PEEK in post-core restorations, PEEK caused less stress in both the tooth and restoration than other post materials because its elastic modulus was close to that of dentin (57). Benli et al. compared post systems fabricated using PEEK, fiber, and metal and observed the highest tensile strength in the PEEK group among restorations completed using appropriate adhesive materials. They noted that there was no significant difference among the failed specimens, and that the bonding failure generally resulted from problems with adhesives (58).

Nahar et al. conducted a study where they compared the von Mises stress distribution was compared among four post systems, including fiber-reinforced composite post (FRC), carbon fiber-reinforced PEEK post (CFR-PEEK), glass fiber-reinforced PEEK post (GFR-PEEK), and prefabricated polyetherketoneketone post (PEKK), used for the restoration of endodontically treated teeth. In that study, under the forces applied, the CFR-PEEK post group exhibited minimal von Mises stress, whereas the PEKK prefabricated post showed maximal von Mises stress in the dentin. Moreover, since the porcelain-fused-to-metal crown (PFM) and PEEK crown displayed comparable stress in the dentin, it was suggested that PEEK crowns can be used as an alternative to PFM crowns (59).

In a study by Ibrahim et al., who examined the biomechanical and thermal stress of the PEEK prefabricated post and commonly used conventional prefabricated glass fiber and titanium posts, the PEEK prefabricated post exhibited less stress in the dentin compared to other post materials, with a lower incidence of vertical root fractures. Additionally, it was observed that the glass fiber post produced the highest temperatures in the restored dental components, followed by prefabricated and titanium posts (60).

Consistently, in a study by Lee et al. comparing the mechanical properties of the PEKK post-core system with gold and glass fiber post-core systems, PEEK exhibited a similar stress distribution in dentin owing to its lower elastic modulus and high resistance to failure (61).

As the PEEK polymer contains 20% ceramic fillers, it has outstanding mechanical properties and good tissue compatibility. One of the most important advantages of the PEEK polymer is that it shows good bonding to dentin tissue when cemented with resin cement. Considering these favorable properties, the PEEK polymer may be a viable alternative for endocrown restorations for teeth

with extensive loss of dental material after root canal treatment (62).

It has been recommended that endocrown restorations be made of reinforced ceramics to achieve esthetic outcomes, durability, and good bonding strength. However, reinforced ceramics are extremely hard and can induce stress accumulation in the tooth. The PEEK material and composite systems exhibit shock-absorbing properties owing to their more flexible structures. In a study using a PEEK framework veneered with indirect resin composite for endocrown restoration of an extensively damaged upper molar, the PEEK material was successfully maintained at a follow-up visit 22 months later. Hence, PEEK may serve as a suitable alternative material for endocrown restorations. In addition, the translucency of PEEK facilitates the detection of secondary caries. Long-term studies are warranted for the wider clinical use of the PEEK material (26). It has been found that the fracture strength of PEEK material is more successful in endocrown treatment than zirconia material (63).

The manufacturing and commercialization of colored PEEK materials can potentially lead to their widespread use in esthetic pediatric appliances with the help of CAD-CAM technologies (1).

In a study by Cekic-Nagas et al., which evaluated the flexural strength of different inlay materials, fiber reinforcement was observed to increase the flexural strength of the dental bridges. Inlay-retained dental bridges made of PEEK using a CAD-CAM fiber block displayed high flexural strength. The compatibility of the PEEK material with adhesive systems is crucial for the adhesion of an inlay restoration to the tooth and for quick repair in the case of a possible fracture or degradation (56).

Because of the low surface energy of PEEK, the surfaces of the PEEK material must be cleaned and roughened to ensure good adhesion between the PEEK and resin composite. Rocha et al. examined the bond strength of PEEK to dentin after different surface treatments and suggested that coating the PEEK surface with silica and sandblasting with aluminum oxide particles produced better adhesion compared to sulfuric acid etching (64). Following appropriate surface roughening, acetone- or phosphate-based methacrylate or tribochemicals may be preferred for lining (65). In addition, it is known that the use of bonding agents to increase bonding has a key role in the adhesion of PEEK to resin materials (66).

Another advantage of PEEK material is that it does not cause wear on the antagonist teeth in short-term clinical follow-ups (67).

3.4. Use of PEEK in jaw defects

The PEEK material can be used in patients with cleft lip/palate defects because of its biocompatibility, low density (1.31 g/cm^3), elastic modulus close to that of human bone, resistance to cracking, easy polishing and processing. Costa-Palau et al. fabricated a maxillary

obturator prosthesis using PEEK for a patient with an extensive oronasal defect and suggested that PEEK can be a viable alternative to conventional materials (68). Similarly, Ding et al. fabricated obturators from PEEK using 3D printers for the treatment of patients (30).

3.5. Use of PEEK in endodontic treatment

It has been observed that polymer tips used for ultrasonic activation in root canal irrigation are associated with a lower risk of fracture and less dentin damage than metal tips. For this reason, tips made of PEEK and polyamide (PA6) have been designed as new-generation polymer tips. Kucher et al. evaluated the chemical resistance of PEEK and polyamide (PA6) against a number of irrigants, including ethylenediaminetetraacetic acid (EDTA) 20%, chlorhexidine gluconate (CHX) 2%, and sodium hypochlorite (NaOCl) 5.2%. Both polymers were found to be resistant to the tested irrigants, with no significant changes in surface and mechanical properties. As a result, they suggested that PEEK can be regarded as a material for reusable irrigation tips, especially because of its structural dynamic characteristics and high chemical resistance (69).

4. Conclusion

Owing to the shortcomings of the existing materials used in dental practice, dentistry is constantly evolving in search of advanced materials. The outstanding features of the PEEK material led to its widespread use in adult dentistry. Owing to additive manufacturing and 3D processes in the era of digitalization, the use of PEEK as an alternative material for pediatric appliances is currently being evaluated. In particular, we believe that with its improved features, PEEK can fulfill esthetic expectations in pediatric dentistry. Since PEEK polymer is a novel material, prospective clinical studies are warranted to confirm its suitability for use in the dental treatment of pediatric patients.

Disclosures

Peer-review: Externally peer-reviewed.

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

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

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

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