OPEN ACCESS

Saudi Journal of Oral and Dental Research
Abbreviated Key Title: Saudi J Oral Dent Res
ISSN 2518-1300 (Print) | ISSN 2518-1297 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article | Orthodontics and Dental Anatomy

Applications of Polyetheretherketone in Orthodontics: A Review of Existing Evidence

Saherish Farhan[1*], Sandhya Maheshwari[2], Mohammad Tariq[2], Aiswareya G[1], Nabeela Ibrahim[1]

[1]Junior Resident, Department of Orthodontics and Dental Anatomy, Dr. Z. A. Dental College, Aligarh Muslim University, Aligarh, India
[2]Professor, Department of Orthodontics and Dental Anatomy, Dr. Z. A. Dental College, Aligarh Muslim University, Aligarh, India

DOI: 10.36348/sjodr.2022.v07i11.006 | **Received:** 04.10.2022 | **Accepted:** 10.11.2022 | **Published:** 14.11.2022

***Corresponding author:** Saherish Farhan
Junior Resident, Department of Orthodontics and Dental Anatomy, Dr. Z. A. Dental College, Aligarh Muslim University, Aligarh, India

Abstract

Introduction: Polyetheretherketone (PEEK) has emerged in the recent years as a promising alternative to currently used biomaterials in the field of medicine and dentistry. Studies are increasingly being undertaken to gain in-depth knowledge about the properties it possess. Critical analysis of the nature of this synthetic material, possible applications and limitations in the branch of orthodontics is needed. ***Objective***: This article is aimed at providing a synthesis of the available literature about the existing evidence that is available concerning the possible applications of polyetheretherketone in the branch of orthodontics. ***Result***: The information obtained from the selected articles was arranged in an organized manner for the ease of understanding under the given subheadings in the article.
Keywords: PEEK, modified PEEK, PEEK and Dentistry, advantages of PEEK, applications of PEEK in orthodontics, PEEK and orthodontics.

INTRODUCTION

In the contemporary world of dentistry, there have been significant advancements in material sciences, both in terms of production of new materials as well as their increasing applications in a growing number of domains. The constant search for a better suited material that fulfills all the ideal requirements has led to the development of quite a few new biomaterials. With continuing search, significant improvements in the materials used earlier have also been accomplished. Yet, none of the materials currently in the market is a perfect blend of all the ideal properties. Biomaterials in orthodontics are expected to have biocompatibility, resilience, corrosion resistance, low plaque affinity, aesthetics, and a variety of other properties depending on their application. Recent years have seen the introduction of a new biomaterial, Polyetheretherketone (PEEK) in the medical field with many promising properties that could be utilized in various specialties if developed properly. Many studies have been published that have tested its properties and its viability as a biomaterial. Several investigations are being undertaken to test this material as an alternative to the current gold standards in various biomedical fields including different branches of dentistry. This article aims to provide a summary of the relevant research and available evidence about the potential applications of polyetheretherketone in the field of orthodontics.

MATERIALS AND METHODS

An electronic literature search was conducted through Medline via PubMed, Wiley Online library, EBSCOhost, Science Direct, as well as Google Scholar between January 2000 and December 2020. Additionally, manual searches in the reference lists of the articles included were also carried out.

Keywords used: "PEEK", "modified PEEK", "PEEK and Dentistry", "advantages of PEEK", "applications of PEEK in orthodontics" , "PEEK and orthodontics".

Eligibility criteria:

1. Only articles in English language were considered.
2. Articles about properties of PEEK useful to orthodontics.
3. Articles about uses of PEEK in dentistry and orthodontics.

4. Invitro, Invivo research articles about application of PEEK in orthodontics.

RESULTS

The search strategy yielded a total of 253 studies. After the removal of duplicates and screening the tittle/abstract [27, 1-6, 8-28], studies met the eligibility criteria and were included in this review. The information obtained from the selected articles was then arranged in an organized manner for the ease of understanding under the given subheadings in the discussion section of the article.

DISCUSSION

PROPERTIES OF POLYETHERETHERKETONE:

Polyetheretherketone (PEEK), structured as (–C6H4–O–C6H4–O–C6H4–CO–)n, is a polyaromatic semi crystalline thermoplastic polymer.[1] Invibio Ltd. (Thornton-Cleveleys, UK) proposed PEEK as a material for biomedical application in 1998. PEEK has outstanding mechanical properties which are preserved at elevated temperatures. It possesses rigidity, opacity as well as other exceptional properties and a wide range of processing options. PEEK is considered to have the potential to overtake metal alloys in the field of dentistry.

In comparison to conventional plastic, a subgroup called Engineering plastics have been utilized widely for industrial use. These super engineering plastics (SEPs) are capable of providing improved mechanical strength, thermal and chemical stabilities useful in the biomechanical discipline as well [2]. Amongst the many categories of SEPs, (PEEK) demonstrates the most noteworthy mechanical strength [3]. Table 1 summarizes mechanical and chemical properties of PEEK.

Table 1: Properties of PEEK

Property	*PEEK*
Tensile Strength	80 MPa [4]
Flexural Strength	140-170 MPa[5]
Modulus of Elasticity	3–4 GPa [6]
Shear Strength	50 MPa [7]
Water Solubility (At Room Temperature)	0.5 w/w % [6]
Water Absorption	0.2 wt.% at 37°C [4] 0.4 wt.% at 121°C [4]
Melting Temperature	334°C [6]
Crystallisation Peak	343°C [6]
Glass Transition Temperature	145°C [6]
Thermal Conductivity	0.29 W/mK [8]
Thermal Expansion	52 µm/m-K[7]
Density	1300 kg/m³ [8]
Rockwell R Hardness	120[7]
Specific Heat Capacity	1700 J/kg-K[7]

PEEK has the ability to combine with other materials to yield improved properties. PEEK composite reinforced with carbon fibres (CFR-PEEK) is an example of this. CFR-PEEK has a larger elastic modulus of 18 GPa which is comparable to human cortical bone and dentin [9]. PEEK's wear resistance was similar to metal alloys despite the low elastic modulus [10]. It has the highest flexural strength and creep resistance of the three types of tested orthodontic wires made of super engineering plastic [11]. The tensile properties of PEEK were found to be identical to those of enamel and dentin [10]. It was also a successful bearing material since it had good fatigue resistance and a low creep rate [11, 12].

Low water solubility of 0.5 percent made PEEK resist chemical destruction. Even at temperatures as high as 260°C, long-term water exposure caused no chemical damage [5]. PEEK's chemical resistance helped to reduce biocorrosion, preventing the release of toxic by- products [13]. Exposure to conventional solvents had no effect on PEEK. PEEK also showed excellent resistance to gamma and electron beams [14], which were used to sterilize medical devices, thanks to its unique aromatic chemical structure. PEEK also created no artefacts on magnetic resonance imaging and X-ray radiographs due to its radiolucency [15]. It is metal free, hence, aesthetic. PEEK's biocompatibility is excellent showing no mutagenic or cytotoxic effects in in vitro studies [16]. It is also a nutritionally certified material that complies with both European and American regulations (FDA).

APPLICATIONS IN MEDICAL AND OTHER DENTAL SPECIALTIES:

In the recent years, PEEK has found itself in use as an advanced biomaterial in many specialties ranging from prosthetic dentistry, orthopedics to trauma, spinal and cranioplastic implant surgery [17, 5, 18]. Case reports of PEEK being used for reconstruction of maxillofacial and cranial defects with the help of computer aided designing and computer aided manufacturing have been presented wherein, detailed implants with complex morphology have been designed and successfully applied [19]. In prosthodontics, PEEK is a relatively new launch which is increasingly being used to fabricate removable partial denture, fixed partial dentures, crowns, implants, individual abutments as well as other complex maxillofacial prosthesis [17, 20].

APPLICATIONS IN ORTHODONTICS

AS ORTHODONTIC ARCHWIRES:

A major part of an orthodontist's inventory comprises of the archwires. Orthodontic movement is a consequence of biomechanics taking place between the archwire and bracket interface, thus making these two constituents the most important part of any fixed appliance. These two components are profoundly dependent on their material properties to carry out the expected movement. In the past years, most commonly used materials for fabrication of orthodontic wires have been stainless steel, Nickel Titanium alloys, Titanium Molybdenum alloy and cobalt Chromium Alloys. Their excellent elastic properties make them the materials of choice. But as years progress, need for an aesthetic alternative is ever-increasing. Also, since metallic wires pose risks with magnetic resonance imaging (MRI), advancement of non-metallic alternatives is required.

As PEEK material rose to the limelight as a dental biomaterial in the recent years, studies were done to better understand its load deflection, friction and other mechanical properties in order to assess its feasibility as an orthodontic wire [11, 21]. Maekawa *et al*., evaluated the viability of using super engineering plastics as arch wires in orthodontic practice [11]. The three types of SEPs they compared were polyether sulfone (PES), polyether ether ketone (PEEK) and polyvinylidene difluoride (PVDF). They intended to study their performance relative to metallic wires commonly used in orthodontics. Results showed that all the types endured comparable forces to Ni-Ti wire and with negligible permanent deformation [11]. The orthodontic force delivered by Polyetheretherketone wires with alike cross-sectional dimensions to metallic orthodontic wires was reported to be a satisfactory approximation of the optimal force required to carry out orthodontic movement [11].

In another study by Tada et al, PEEK wires of orthodontic dimensions size and shape wise, were studied for load-deflection characteristics [21]. Frictional properties were also looked into and the results were weighed against Ni-Ti. Simulating the initial stages of orthodontic treatment, three-point bending tests were carried out and it was inferred that 0.019 x 0.025 inch PEEK wire exhibited almost entirely similar properties with Ni-Ti wire [21]. 0.019 x 0.025 inch PEEK appeared to have a higher load as compared to Ni-Ti in slot-lid (SL) ligation. This study also proposed that 0.019 x 0.025 inch PEEK tooth movement might be more effectual than Ni- Ti tooth movement. Tooth movement is more effective when there is less permanent deformation. With SL ligation, the amount of permanent deformation of PEEK wires was comparable to that of Ni-Ti wires. The load reduction of 0.016 x 0.022 inch PEEK and 0.019 x 0.025 inch PEEK was greater than that of Ni-Ti in stress relaxation tests. However, 70–80% of the original load was well-kept-up, and the preserved value was adequate for orthodontic needs.

Further, studies also suggested that covering of commonly used clinical wire materials could be covered up tubing made out of polyetheretherketone. [22] Utilizing diverse types of standard arch wires with and without the PEEK tubing, the aesthetic character and effect of frictional forces on bracket base were evaluated. When the SS and Co-Cr wires were covered with the PEEK tube, they had notably lower friction values. Following the friction force test, the surface roughness of a wire covered by a PEEK tube changed very little. The colour difference in the PEEK tube was virtually indistinguishable to that of coated wires commonly used in clinical practice, demonstrating that it had appropriate aesthetic properties. They concluded that such use of PEEK tubing/layer in orthodontic appliances exhibited a good blend of aesthetic and operational properties.

AS RETAINERS

PEEK, which bonds well to composite after simple preparation, may help restraint the relapse tendencies observed with current retainers. When processed using computer-aided design/computer-aided manufacturing (CAD/CAM), PEEK exhibits lesser deformations and withstands greater fracture loads in comparison to that processed using other methods [23].

By relating its functioning to that of other retainer wires and optimising its bond to composite adhesive materials, a study by Kadhum *et al*., looked into the effectiveness of polyether-ether- ketone (PEEK) wire as a fixed orthodontic retainer [24]. Three separate metallic retainer wires were compared in three tests: two tests quantified debonding force and associated wire deflection from acrylic blocks and bovine teeth, and one test evaluated pull-out force from acrylic blocks and bovine teeth. They concluded that when bonded with 4 mm composite bonding spots, the 0.8 mm round PEEK wires have analogous performance to conventional retainers in terms of debonding and pull-out forces; utilising air-abrasion for 10 s at 3.5 MPa delivered appropriate bond of the composite to the wire. This study illustrated the possible use of PEEK material as a fixed retaining appliance for improved post treatment retention. This was also the first study to have performed an in vivo experiment to study the performance of PEEK with different surface treatment as fixed retainer. However, the use of bovine teeth instead of human teeth remained a limitation.

AS SPACE MAINTAINERS:

In a Pilot study by Ierardo *et al*., with a goal to create orthodontic space maintainers out of PEEK polymer, digital system (CAD/CAM) was used and nine month- follow up of the devices was done [25]. Three prototypes of the retainers were created, lingual arch, band with loop and removable plate. Because the devices were personalized and barely visible, all three patients found them to be very comfortable and satisfying after a nine-month follow-up. These devices were found to be adequate for space preservation. They stayed stable after that, with no signs of dis-cementation or fracture as well as, no mention of an allergy or of plaque. The devices were well received by all patients due to their smooth surface, as well as the ease with which they could be polished and cleaned. PEEK was discovered to be an excellent material for building space maintainers due to its dimensional stability, mechanical strength, and, most importantly, biocompatibility.

In a study by Guo *et al*., PEEK was used in the production of digital removable space maintainer (RSM) [26]. Because of its good physiochemical, mechanical, and biological performance, as well as the ease with which it can be cut and moulded using CAD/CAM technology, PEEK has been used in prosthodontics for the construction of denture bases to a great extent. It is reliable and uncomplicated to make for children, and it may be better-quality than the methods that use artificial teeth and self-curing resin. They observed that RSMs created by means of the digital design and integration method were proved to be better to the ones fashioned by means of the traditional method. The outcomes of the 3D variation analysis revealed that the PEEK groups' mean distances and standard deviations were substantially lower than those of the conventional group. They concluded that a PEEK-manufactured space maintainer created with computer aided designing would be optimal for clinical purposes.

PROJECTED FUTURE POSSIBILITIES AND LIMITATIONS:

In comparison to PMMA (polymethylmethacrylate) based materials, PEEK has exhibited lower solubility and water absorption [27]. This indicates its possible future use as their alternative in removable orthodontic appliances. Finite element analysis has revealed that prosthodontic implants made out of carbon reinforced PEEK result in less stress shielding effect than titanium implants [28]. This property can be further explored and applied to orthodontic implants as well. With progression in use of PEEK as a prosthesis material, another possible research area that requires to be probed is how such prosthetically treated teeth will be managed in orthodontic treatment during bonding and debonding. Proper techniques to deal with such interdisciplinary situations, if required in the near future, need to addressed.

Limitations in the usage of PEEK in orthodontics involve the cost aspect and the limited aesthetical capability of PEEK. The cost factor also subsidizes the extent of research done on it. PEEK has shown limited bonding capability to composite which restricts its use in many dental applications. The existing data about PEEK in orthodontics, though exhilarating, lacks substantial high-quality evidence. Recent developments and increasing research on PEEK and its polymers are all aimed at improving it to a point where it can overtake conventional materials in terms of usage. Further researches, in vivo clinical trials and long-term studies are needed to further validate the use of PEEK as a part of an orthodontist's everyday armamentarium.

CONCLUSION

Despite being a recently introduced dental material, PEEK has made a promising name for itself in a short time. The exceptional physical and chemical properties that are compatible with its use in orthodontic applications, though improvement is still required in the aesthetic attribute. PEEK has great potential as evidenced by the recent development and commercialization which promises major improvement in this aesthetic shortfall.

REFERENCES

1. Fan, J. P., Tsui, C. P., Tang, C. Y., & Chow, C. L. (2004). Influence of interphase layer on the overall elasto-plastic behaviors of HA/PEEK biocomposite. *Biomaterials*, *25*(23), 5363-5373.
2. Boyaci San, F. G., & Tekin, G. (2013). A review of thermoplastic composites for bipolar plate applications. *International journal of energy research*, *37*(4), 283-309.
3. Shirakawa, N., Iwata, T., Miyake, S., Otuka, T., Koizumi, S., & Kawata, T. (2018). Mechanical properties of orthodontic wires covered with a polyether ether ketone tube. *Angle Orthodontist*, 88(4), 442–449.
4. Qin, L., Yao, S., Zhao, J., Zhou, C., Oates, T. W., Weir, M. D., ... & Xu, H. H. (2021). Review on development and dental applications of polyetheretherketone-based biomaterials and restorations. *Materials*, *14*(2), 408.
5. Kurtz, S. M., & Devine, J. N. (2007). PEEK biomaterials in trauma, orthopedic, and spinal implants. *Biomaterials*, 28, 4845–4869.
6. Panayotov, I. V., Orti, V., Cuisinier, F., & Yachouh, J. (2016). Polyetheretherketone (PEEK) for medical applications. *Journal of Materials Science: Materials in Medicine*, 27(7).
7. https://www.makeitfrom.com/material-properties/Unfilled-PEEK
8. Garcia-Gonzalez, D., Rusinek, A., Jankowiak, T., & Arias, A. (2015). Mechanical impact behavior of

polyether–ether–ketone (PEEK). *Composite Structures*, *124*, 88-99.

9. Schwitalla, A., & Müller, W. D. (2013). PEEK dental implants: a review of the literature. *Journal of Oral Implantology*, *39*(6), 743-749.
10. Alexakou, E., Damanaki, M., Zoidis, P., Bakiri, E., Mouzis, N., Smidt, G., & Kourtis, S. (2019). PEEK high performance polymers: A review of properties and clinical applications in prosthodontics and restorative dentistry. *Eur. J. Prosthodont. Restor. Dent*, *27*, 113-121.
11. Maekawa, M., Kanno, Z., Wada, T., Hongo, T., Doi, H., Hanawa, T., Ono, T., & Uo, M. (2015). Mechanical properties of orthodontic wires made of super engineering plastic. *Dent Mater J*, 34, 114-119.
12. Werner, P., Altstädt, V., Jaskulka, R., Jacobs, O., Sandler, J. K., Shaffer, M. S., & Windle, A. H. (2004). Tribological behaviour of carbon-nanofibre-reinforced poly (ether ether ketone). *Wear*, *257*(9-10), 1006-1014.
13. Ouyang, L., Zhao, Y., Jin, G., Lu, T., Li, J., Qiao, Y., ... & Liu, X. (2016). Influence of sulfur content on bone formation and antibacterial ability of sulfonated PEEK. *Biomaterials*, *83*, 115-126.
14. Buck, E., Li, H., & Cerruti, M. (2020). Surface modification strategies to improve the osseointegration of poly (etheretherketone) and its composites. *Macromolecular bioscience*, *20*(2), 1900271.
15. Rahmitasari, F., Ishida, Y., Kurahashi, K., Matsuda, T., Watanabe, M., & Ichikawa, T. (2017). PEEK with reinforced materials and modifications for dental implant applications. *Dentistry journal*, *5*(4), 35.
16. Katzer, A., Marquardt, H., Westendorf, J., Wening, J. V., & Von Foerster, G. (2002). Polyetheretherketone—cytotoxicity and mutagenicity in vitro. *Biomaterials*, *23*(8), 1749-1759.
17. Najeeb, S., Zafar, M. S., Khurshid, Z., & Siddiqui, F. (2016). Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. *Journal of prosthodontic research*, *60*(1), 12-19.
18. Zhang, J., Tian, W., Chen, J., Yu, J., Zhang, J., & Chen, J. (2019). The application of polyetheretherketone (PEEK) implants in cranioplasty. *Brain research bulletin*, *153*, 143-149.
19. Kim, M. M., Boahene, K. D., & Byrne, P. J. (2009). Use of customized polyetheretherketone (PEEK) implants in the reconstruction of complex maxillofacial defects. *Archives of facial plastic surgery*, 53-57.
20. Costa-Palau, S., Torrents-Nicolas, J., Brufau-de Barberà, M., & Cabratosa-Termes, J. (2014). Use of polyetheretherketone in the fabrication of a maxillary obturator prosthesis: a clinical report. *The Journal of prosthetic dentistry*, *112*(3), 680-682.
21. Tada, Y., Hayakawa, T., & Nakamura, Y. (2017). Load-deflection and friction properties of PEEK wires as alternative orthodontic wires. *Materials*, 10(8), 1–12.
22. Shirakawa, N., Iwata, T., Miyake, S., Otuka, T., Koizumi, S., & Kawata, T. (2018). Mechanical properties of orthodontic wires covered with a polyether ether ketone tube. *The Angle Orthodontist*, *88*(4), 442-449.
23. Stawarczyk, B., Thrun, H., Eichberger, M., Roos, M., Edelhoff, D., Schweiger, J., & Schmidlin, P. R. (2015). Effect of different surface pretreatments and adhesives on the load-bearing capacity of veneered 3-unit PEEK FDPs. *The Journal of Prosthetic Dentistry*, 114(5), 666–673.
24. Kadhum, A. S., & Alhuwaizi, A. F. (2021). The efficacy of polyether-ether-ketone wire as a retainer following orthodontic treatment. *Clinical and experimental dental research*, *7*(3), 302-312.
25. Ierardo, G., Luzzi, V., Lesti, M., Vozza, I., Brugnoletti, O., Polimeni, A., & Bossù, M. (2017). Peek polymer in orthodontics: A pilot study on children. *Journal of Clinical and Experimental Dentistry*, 9(10), e1271–e1275.
26. Guo, H., Wang, Y., Zhao, Y., & Liu, H. (2020). Computer-aided design of polyetheretherketone for application to removable pediatric space maintainers. *BMC Oral Health*, 20(1), 1-10.
27. Liebermann, A., Wimmer, T., Schmidlin, P. R., Scherer, H., Löffler, P., Roos, M., & Stawarczyk, B. (2016). Physicomechanical characterization of polyetheretherketone and current esthetic dental CAD/CAM polymers after aging in different storage media. *The Journal of prosthetic dentistry*, *115*(3), 321-328.
28. Lee, W. T., Koak, J. Y., Lim, Y. J., Kim, S. K., Kwon, H. B., & Kim, M. J. (2012). Stress shielding and fatigue limits of poly-ether-ether-ketone dental implants. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, *100*(4), 1044-1052.