RESEARCH PAPER

POLYETHER KETONE FOR DENTAL IMPLANT SCREWS: A CRITICAL REVIEW

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ABSTRACT

Polyaryletherketone (PEK) materials have been extensively used in dynamic load-bearing applications in orthopaedics; however, their use as a dental implant screw is still not successful in its pure form. Formation of composites with bioceramics has been advocated and used; however, with the risk of delamination and resorption of ceramic particles over time. One possible great solution for making clinically successful dental implants with PEK polymers is to modify them with chemical techniques to result in a robust, fully polymeric implant material that matches the required mechanical properties. This critical review focuses on a careful comparison of the mechanical properties of bone, PEK polymers, and titanium to point out essential factors that prevent translation of PEK polymers to dental implant screws and arrive at possible methods to improve the properties of PEK polymers.

Keywords: PEEK, PEKK, Dental implants, Screws, Mechanical.

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INTRODUCTION

The world of dental implants is dominated by titanium alloys, and is now slowly being explored by zirconia-based implants. The major reason for this dominance by metal is that the amount of mechanical properties required for an implant screw is easily satisfied only by metals, and to some extent, ceramics. The polymer class of materials is not even thought about for such applications. However, the advent of the modern class of high polymers does question this paradigm, since they possess properties similar to bone .[1] High mechanical properties of titanium are reported to cause a stress shielding effect in bone.[2] Further, titanium is known to cause an allergy in about 0.6% of patients.[3] Further, the cost factor of titanium implant manufacturing is high, making the standard of care unaffordable to many classes of society.

For solving these pertinent issues, alternative materials are constantly explored, of which polymers are a promising class for the purpose. Especially, poly aromatic ether ketone [PEK] group of polymers is advantageous due to clinically known biocompatibility towards bone tissue in the past two decades. It can be easily fabricated at low cost and custom-made for patient applications.[4] Their properties reach those of bone, spiking interest in their use as implant screws. The major question of the current critical review is that, despite the use of PEK-based polymers in clinical orthopaedics and dental implant parts, they have still not made their presence in the arena of dental implant screws. This review attempts to critically assess the obstacles in the clinical translation of pure PEK polymers for dental implants from the research scale analysis.[5]

Modifications of PEEK for improving mechanical properties

Modification of PEEK in bulk has been extensively explored in the literature and has been considered as the primary strategy to circumvent its inherent bio-inertness and inadequacies in mechanical properties. Among these modifications, the addition of hydroxyapatite is one of the commonly investigated additions. owing to its close chemical similarity to the mineralized part of the bone. PEEK with hydroxyapatite composites has been shown as a promising candidate for biomaterials placed in bone by numerous studies, especially in load-bearing applications. It has been repeatedly shown that the addition of HA contributes both to biological activity and to the improvement in mechanical behaviour. This does require optimization in filler dispersion and interfacial bonding.[6] The hydroxyapatite phase in biomaterials in general and PEEK in specific plays a vital role in osteogenesis, which happens by promoting favourable protein adsorption and osteoblast adhesion. When the ambience of cells is optimal, the cells proceed with extracellular matrix deposition and mineralization. When such a phenomenon happens, the mineralized bone tissue is deposited in closer proximity, manifesting as improved integration at the bone–implant interface. This critically contributes to the longevity of clinical service of the material.[7] This has led to the proposal of PEEK-HA composites as suitable substitutes for cortical bone. Investigators have also taken this material to the next level - the in vivo evaluation. For example, Geng et al. (2020) have evaluated PEEK/HA implants in a canine tibial model and reported significantly increased bone formation and bone–implant contact. The changes in biological activity were attributed to the presence of HA in the composite.[8]

Further advancements in PEEK have been achieved by structural modifications, including the introduction of three-dimensional porous architectures in these composites. The presence of controlled porosity typically facilitates nutrient diffusion, neovascularization, and osteoblast differentiation. It therefore improves the biological response towards the material.[9] Beyond conventional HA incorporation, numerous studies have explored different forms and deposition strategies of hydroxyapatite on PEEK matrices like nano-HA, surface-functionalized HA, and gradient composites.[10-12]

With the same mechano-biological effect of HA, other bioactive fillers have also been investigated, both as alternatives and as adjuncts to HA. Bioglass, calcium silicates, and other silicate-based ceramics have demonstrated similar effects with PEEK. These materials are also known for their ion-releasing property that stimulates cellular responses towards apatite formation in physiological environments. Their addition into PEEK as fillers has improved osteogenic differentiation and has in some cases shown to be of superior mechanical outcomes compared with HA alone.[13]

In order to address the aforementioned mechanical and biological limitations of PEEK, fiber reinforcement strategies have been widely investigated. Carbon fiber–reinforced PEEK (CFR-PEEK) has recently emerged as a promising candidate owing to its significantly enhanced mechanical properties. The mechanical properties can be tailored by varying fiber content, orientation, and distribution within the polymer matrix.[14-16] These composites have achieved mechanical properties closer to those of cortical bone, reducing the stress shielding effect along with sufficient load-bearing capacity. Several studies have also proposed the use of CFR-PEEK in dental implant screws, critically highlighting its potential to withstand functional occlusal loads.[17] A rather similar approach has been seen with glass fiber–reinforced PEEK (GFR-PEEK), which has also shown enhanced mechanical properties, slightly less than carbon fiber reinforcement. However, GFR-PEEK has other advantages such as aesthetics and radiolucency, making it an alternative in specific clinical scenarios.[18]

While the findings discussed so far may seem promising, challenges remain in achieving the balance between mechanical performance and biological activity. Ma et al. (2020) have shown this in their comprehensive review of various PEEK modification strategies such as composites with hydroxyapatite, carbon fibers, zinc oxide, bioactive glass, titanium dioxide particles, and nano-silicates.[19] The authors have noted that most of these technologies are still “immature,” particularly when analysed in terms of scalability, reproducibility, and long-term clinical validation. This has underscored the requirement for more efficient, practical, and standardized modification techniques for translation from experimental research to clinical use.

Along with various bulk modification techniques, surface modification techniques have also been extensively reported for enhancing the biocompatibility of PEEK. These methods do not modify the bulk material, but act only on the outermost surface layer that interacts with the biological system. Therefore, these techniques preserve the intrinsic advantages of the polymer. Commonly explored surface modification techniques include sulfonation, plasma treatment, accelerated neutral atom beam (ANAB) treatment, acid etching, and application of bioactive coatings.[19] Surface sulfonation is commonly achieved with concentrated sulfuric acid, and it introduces a porosity that is lined by a chemically active layer on the PEEK surface. It significantly improves hydrophilicity and thereby promotes cell attachment. Plasma treatment is another widely used approach, which involves exposure of material surfaces to ionized gases. This technique changes both the surface physics and chemistry, such as increased surface roughness, attachment of functional groups, and enhanced surface energy, all of which contribute to improved favourable protein adsorption, consequent cell adhesion, and overall osteo-compatibility.[20, 21] Therefore, plasma treatment is a versatile and valuable tool in surface engineering of PEEK.

The accelerated neutral atom beam (ANAB) technique provides a more precise and minimally invasive method for surface modification. It alters the surface at nanometre-scale depths (2–3 nm) and preserves the bulk properties while significantly enhancing surface bioactivity. ANAB-treated PEEK surfaces typically exhibit improved cell adhesion, proliferation, and mineral deposition.[22] Likewise, acid etching methods have also shown significant improvements in surface roughness and wettability, leading to enhanced biological responses.[23, 24]

Beyond all these mentioned techniques, surface coatings have been extensively researched for imparting bioactivity to PEEK. Coating of polymer surface with materials like titanium, titanium dioxide, hydroxyapatite, zirconium phosphate, and silicon nitride has been performed by various techniques such as plasma spraying, sputtering, and dip coating.[25- 28] These coatings attempt to mimic the surface of conventional metallic implants, retaining the polymeric underlying structure. Obviously, these have shown improved cell attachment, proliferation, and bone–implant contact in experimental studies.

With all these surface and bulk modification techniques, PEEK has reached the stage of being used in dental implant screws; however, it has not yet been translated clinically. One factor that may prevent clinical translation is that the material should intrinsically possess these properties, as modifications can have disadvantages. The major reason for contemplating pure polymers is to prevent the disadvantages of bonding issues in composite formation, like delamination between the matrix and the reinforcing agent. Modification of the polymer can afford many more mechanical advantages compared to composites. A pristine polymeric implant material has certain practical advantages relating to the long-term mechanical and biological stability. Major benefits lie in its homogeneity, which presents as a single-phase structure. Therefore, it eliminates the mechanical complications of interfacial boundaries present in reinforced composites. These interfaces are technically stress-concentrating regions and are predisposed to microcrack initiation. This may lead to delamination and fatigue failure, especially under cyclic masticatory loads. Homogeneous polymers present themselves as more predictable materials when it comes to stress distribution.

The next critical aspect is the surface stability of the implant material. In the case of composites, exposure and consequent degradation of the reinforcing phases at the material surface may present as altered biological responses. This chemical alteration of exposed fillers can change the wettability over time and can lead to low-grade inflammatory reactions that are detrimental to long-term clinical service. In composite implants, exposure of reinforcing phases at the surface at various stages such as manufacturing, placement in bone, and clinical service, can lead to the formation of microdomains with differences in biological affinities. Pristine polymers, when modified using controlled chemical methods, can offer a uniform and more importantly, predictable biological response over time. Processing becomes more controllable and reliable with pure polymers due to fewer variables affecting the reproducibility. Pristine polymers are devoid of concerns regarding particle release and long-term interfacial degradation, positioning the pure polymer materials as more reliable, biologically acceptable, and mechanically capable candidates for dental implant materials. Summarily, PEEK has been made into composites with calcium phosphate ceramics for custom implant making.[29] However, the long-term success is in question because of the aforementioned reasons. However, carbon fiber may be a viable alternative to these ceramics due to biological and chemical stability. These materials may be seen as evolutionary materials until a pure polymeric implant is formed.

Analysis of mechanical and biological properties

These PEK class of polymers are made of aromatic benzene rings connected by ether or ketone bridges.[30, 31] The ether group and ketone group are chemically different and hence contribute differently to mechanical properties. Ether groups increase the flexibility and reduce the toughness of the final polymer. These groups increase chain mobility due to a low rotational energy barrier, increased torsional freedom leading to increased toughness and ductility, and significantly reduce elastic modulus. The oxygen group in the ether moiety does not form strong dipole interactions, thereby reducing chain-chain packing efficiency, crystallinity and, hardness. It also lowers the glass transition [Tg] due to higher mobility of chains, making it more workable but less stiff final product. On the other hand, ketone groups increase stiffness, strength, and thermal resistance due to their rigid, highly polar, and planar nature, creating more ordered and cohesive chains. It provides a rod-like backbone, elevating the stiffness, tensile, and compressive strengths. It has more intermolecular interactions and can increase chain packing, crystallinity potential, and consequent higher hardness and wear resistance. It also elevates the glass transition temperature [Tg] due to restriction of freedom of movement. It makes the final product more brittle.[32, 33] Therefore, there should be a balance between these groups to arrive at a workable polymer. Ether to ketone ratios having slightly more ketone groups, like 1:1.2, may be needed to achieve higher mechanical properties. Table 1 below compares key mechanical properties among the materials.

Table 1: Comparative mechanical properties[34, 35]

Property	Cortical Bone	PEEK	PEKK
Elastic modulus [GPa]	10–20	3–4	5–12 [deper crystallinity
Tensile strength [MPa]	70–150	90–100	110–150
Compressive strength	100–230	110–120	150–200

[MPa]				
Shear strength [MPa]	50–70	~40	50–70	200–250
Hardness [Vickers HV]	40–70	20–30	25–45	200–350
Fracture toughness [MPa√m]	2–12	2–4	2–5	55–115
Fatigue strength [MPa]	30–70	~60	70–120	450–600
Creep resistance at 37°C	High [quasi-elastic]	Moderate–poor	Good–very good	Excellent
Wear resistance	Moderate	Low	Moderate	High
Density [g/cm³]	1.9	1.3	1.3–1.4	4.4–4.5
Surface energy [mN/m]	40–50	~20	20–30	40–55
Modulus mismatch vs bone	None	Too flexible	Close [optimized grades only]	Too stiff causes stress shielding

From the biological point of view, the elastic modulus of implant screws should be close to that of cortical bone. For a whole tooth, the mechanical properties may be much higher than bone; however, due to the presence of the intervening periodontal ligament, the stress is properly distributed. In the case of osseointegrating implants, due to the absence of soft tissue in between, the force is directly transferred to the underlying bone, and a high elastic modulus leads to stress shielding, typically in titanium. PEEK in this regard is overly flexible, leading to poor primary stability and thread deformation, whereas PEKK polymers can be tuned to acheive an elastic modulus closest to bone.[34, 35]

About mechanical Strength properties, PEKK has properties adequate for moderate loading, whereas PEEK has borderline properties for screw threads. For preservation of the thread during insertion, the screw material should be of higher hardness. In both these aspects, titanium is the best; however, PEKK is favourable. As one can assume, titanium exhibits extremely high fatigue strength, creep, and deformation under load properties, and PEKK is suitable but not comparable to it. Hence, PEKK may be the optimal polymer candidate, requiring geometric optimisation, surface modification, crystallinity tuning, and possible bulk copolymerization.[36]

Polymer chemistry strategies to improve the mechanical properties of PEK polymers

Multiple chemical strategies are required to improve the mechanical properties of PEK-based polymers. The beauty of polymer science lies in its ability to modify the polymer physics and chemistry according to the requirement.[37] An increase in ketone groups and molecular weight can toughen the final product. It may be advised to reach about 105 gm/mol for the best results.[38, 39] In addition, better crystallinity can offer better mechanical properties.[40] Various techniques of crosslinking can prevent the slippage of chains on one another, making the final product stronger.[41] Co-polymerisation with useful monomers that can cross-link, help compaction, and add biological functionality to the polymer which are extremely useful.[42] Some of the probable means are listed in the Table 2 below.[36,43-46]

Table 2: Polymer chemistry techniques to improve the mechanical properties of PEK polymers

Sl No.	Technique/Mechanism	Principle of strengthening
1	Increase fraction of ketone linkages in backbone[26]	Ketones increase chain rigidity, dipole–dipole interactions, and packing, leading to higher glass transition temperature, modulus, hardness and reduced creep
2	Increase chain entanglement density[43]	More entanglements resist plastic flow, raise tensile strength, and toughness and lower creep
3	Grow larger or more ordered crystalline domains [44]	Crystalline domains act as rigid reinforcement, leading to increased modulus, hardness, dimensional stability, decrease creep
4	Radiation crosslinking to create a light permanent network that limits chain sliding [45]	Crosslinks strongly restrict long-term viscous flow [creep] and stabilize geometry under load
5	Generate radicals that recombine to form interchain crosslinks[45]	Non-chemical route to form bonds, increases hardness, reduces creep, can improve fatigue resistance
6	Introduce strong reversible H-bonding clusters that form transient networks[46]	Reversible bonds act as dynamic crosslinks—improve toughness, dissipate energy, heal microdamage and enhance fatigue life without permanent embrittlement
7	Install ionic groups [–SO₃H, –COO⁻] that pair with multivalent cations to form ionic crosslinks [45]	Ionic associations provide reversible strong interactions leading to raised modulus and damping while preserving some toughness
8	Add monomers that promote π–π interactions or H-bond arrays[36]	Stronger inter-chain interactions improve packing, glass transition temperature, modulus and creep resistance
9	Covalently attach tiny aromatic oligomers that act as nucleation sites for controlled crystallites.[46]	Produces finer, more uniform crystalline morphology [smaller spherulites] leading to better toughness & fatigue

Use of backbone chemistry tuning, higher molecular weight, controlled crystallinity, network chemistry [covalent or supramolecular], and strong interchain interactions can raise the mechanical properties modulus of PEK polymers to values closer to bone.

Limitations of PEK, recommendations, and future directions

PEK polymers may have to be synthesized with higher ketone, higher molecular weight, crosslinks, etc as discussed earlier, and surface chemistry alteration to make the surface osteoconductive is advantageous, and it can be achieved by surface phosphonation, sulphonation, amination, and carboxylation. Substantial chemical modification may invite revision of the entire specification, and the biocompatibility test may have to be repeated.

Evaluation may have to include mechanical (tensile, fatigue, creep), interfacial (thread performance, adhesion), physicochemical (XPS, AFM), and biological (ISO 10993, in vivo osseointegration) assessments.

Conclusions

While a fully-polymeric PEEK implant screw can be called an ambitious goal, chemical strategies can substantially improve PEEK's properties, reaching at least the lower range of cortical bone mechanical behaviour. With proper progress, a well-performing PEK dental implant screw can be achieved. This critical review has exposed the clinical need for material scientists and material characteristics to clinicians, encouraging polymer scientists to explore the PEK materials for dental screws. It is crucial to be aware that the translational trajectory of said materials heavily depends not only on the mechanical refinement but also on the long-term biological validation, especially under simulated functional loading conditions. Also, the standardization of surface modification protocols are essential for regulatory acceptance. This demands a seamless cooperation among material scientists, bioengineers, and clinicians for bridging the lacuna between laboratory innovation and the chair-side translation.

The shift towards high-performance polymers from metal-based materials is a clear example of a paradigm shift in dental implantology. This change is driven by a preference towards compatibility and flexibility alongside strength. Clearly, the future may be dominated by PEK-based systems, not as alternatives to metals and ceramics but as next-generation solutions for dental implant design and application.

References

1. Zhu H, Liu Z, Lu M, Han X, Zhang S: Exploring PEKK: properties, applications and promise of personalized medicine. J Mater Chem B. 2025 Jul. 10:7934-7952. doi: 10.1039/d5tb00596e
2. Niinomi M, Nakai M: Titanium-Based Biomaterials for Preventing Stress Shielding between Implant Devices and Bone. Int J Biomater. 2011, 2011:836587. doi: 10.1155/2011/836587
3. Comino-Garayoa R, Cortés-Bretón Brinkmann J, Peláez J, López-Suárez C, Martínez-González JM, Suárez MJ: Allergies to titanium dental implants: what do we really know about them? A scoping review. Biology. 2020, 18:404. doi: 10.3390/biology9110404
4. Yang Z, Guo W, Yang W, Song J, Hu W, Wang K: Polyetheretherketone biomaterials and their current progress, modification-based biomedical applications and future challenges. Materials & Design. 2025, 20:113716. doi: 10.1016/j.matdes.2025.113716
5. Marya K, Dua JS, Chawla S, Sonoo PR, Aggarwal A, Singh V. Polyetheretherketone (PEEK) dental implants: a case for immediate loading. International journal of oral implantology and clinical research. 20151, 2:97-103. doi: 10.5005/jp-journals-10012-1043
6. Kang J, Zheng J, Hui Y, Li D. Mechanical Properties of 3D-Printed PEEK/HA Composite Filaments. Polymers (Basel). 2022 Oct 12;14(20):4293. doi: 10.3390/polym14204293.
7. Dey, S. K., S, S. K., Sen, I., & Samanta, S. (2022). Mechanical characterisation of PEEK-HA composite as an orthopaedic implant. Advances in Materials and Processing Technologies, 8(3), 3470–3493. doi: 10.1080/2374068X.2021.1970990
8. Geng YM, Ren DN, Li SY, Li ZY, Shen XQ, Yuan YY. Hydroxyapatite-incorporation improves bone formation on endosseous PEEK implant in canine tibia. J Appl Biomater Funct Mater. 2020 Jan-Dec;18:2280800020975172. doi: 10.1177/2280800020975172.
9. Liu X, Ouyang L, Chen L, Qiao Y, Ma X, Xu G, Liu X. Hydroxyapatite composited PEEK with 3D porous surface enhances osteoblast differentiation through mediating NO by macrophage. Regen Biomater. 2021 Dec 16;9:rbab076. doi: 10.1093/rb/rbab076.
10. Zhao L, Hu J, Gao L, Wang J, Ma X, Liu Y, Ao Y, Yan F, Liu L. Improvement of Interfacial Properties and Bioactivity of CF/PEEK Composites by Rapid Biomineralization of Hydroxyapatite. ACS Biomater Sci Eng. 2023 Jul 10;9(7):4117-4125. doi: 10.1021/acsbiomaterials.2c00881.
11. Addai Asante N, Wang Y, Bakhet S, Kareem S, Owusu KA, Hu Y, Appiah M. Ambient temperature sulfonated carbon fiber reinforced PEEK with hydroxyapatite and reduced graphene oxide hydroxyapatite composite coating. J Biomed Mater Res B Appl Biomater. 2021 Dec;109(12):2174-2183. doi: 10.1002/jbm.b.34865.
12. Frankenberger T, Graw CL, Engel N, Gerber T, Frerich B, Dau M. Sustainable Surface Modification of Polyetheretherketone (PEEK) Implants by Hydroxyapatite/Silica Coating-An In Vivo Animal Study. Materials (Basel). 2021 Aug 16;14(16):4589. doi: 10.3390/ma14164589.
13. Taymour N, Fahmy AE, Gepreel MAH, Kandil S, El-Fattah AA. Improved Mechanical Properties and Bioactivity of Silicate Based Bioceramics Reinforced Poly(ether-ether-ketone) Nanocomposites for Prosthetic Dental Implantology. Polymers (Basel). 2022 Apr 18;14(8):1632. doi: 10.3390/polym14081632.
14. Hamsho W, Raufi MY, Alnajjar M, Rhodes M, Hafeez U, Aurangzeb R. Carbon Fiber-Reinforced Polyetheretherketone (PEEK) vs. Titanium Plates for Upper Limb Fractures: A Systematic Review. Cureus. 2026 Jan 8;18(1):e101094. doi: 10.7759/cureus.101094.
15. Li CS, Vannabouathong C, Sprague S, Bhandari M. The Use of Carbon-Fiber-Reinforced (CFR) PEEK Material in Orthopedic Implants: A Systematic Review. Clin Med Insights Arthritis Musculoskelet Disord. 2015 Feb 23;8:33-45. doi: 10.4137/CMAMD.S20354.
16. Clunk MJ, Gonzalez MR, Denwood HM, Werenski JO, Sodhi A, Hoffman BA, Merchan N, Lozano-Calderon SA. A PEEK into carbon fiber: A practical guide for high performance composite polymeric implants for orthopaedic oncology. J Orthop. 2023 Sep 29;45:13-18. doi: 10.1016/j.jor.2023.09.011.
17. Bilginaylar K, Ayali A. Biomechanical behavior of carbon fiber-reinforced polyetheretherketone as a dental implant material in implant-supported overdenture under mandibular trauma: A finite element

analysis study. Niger J Clin Pract. 2023 Oct;26(10):1538-1546. doi: 10.4103/njcp.njcp_239_23.

18. Haseeb SA, Kumar AS, Chaitra MP, Vinaya KC, Gudal SS, Rahmam FP, Babaji P. Finite element analysis to assess stress and deformation in bone with glass fiber-reinforced-poly-ether-ether-ketone, zirconia, and titanium implants. Tzu Chi Med J. 2022 Dec 27;35(3):231-236. doi: 10.4103/tcmj.tcmj_184_22.
19. Ma Z, Zhao X, Zhao J, Zhao Z, Wang Q, Zhang C. Biologically Modified Polyether Ether Ketone as Dental Implant Material. Front Bioeng Biotechnol. 2020 Dec 18;8:620537. doi: 10.3389/fbioe.2020.620537.
20. Novotna Z, Reznickova A, Rimpelova S, Vesely M, Kolska Z, Svorcik V. Tailoring of PEEK bioactivity for improved cell interaction: plasma treatment in action. RSC advances. 2015;5(52):41428-36. doi: 10.1039/c5ra03861h
21. Waser-Althaus J, Salamon A, Waser M, Padeste C, Kreutzer M, Pieles U, Müller B, Peters K. Differentiation of human mesenchymal stem cells on plasma-treated polyetheretherketone. J Mater Sci Mater Med. 2014 Feb;25(2):515-25. doi: 10.1007/s10856-013-5072-5.
22. Khoury J, Maxwell M, Cherian RE, Bachand J, Kurz AC, Walsh M, Assad M, Svrluga RC. Enhanced bioactivity and osseointegration of PEEK with accelerated neutral atom beam technology. J Biomed Mater Res B Appl Biomater. 2017 Apr;105(3):531-543. doi: 10.1002/jbm.b.33570.
23. Torstrick FB, Lin ASP, Potter D, Safranski DL, Sulchek TA, Gall K, Guldberg RE. Porous PEEK improves the bone-implant interface compared to plasma-sprayed titanium coating on PEEK. Biomaterials. 2018 Dec;185:106-116. doi: 10.1016/j.biomaterials.2018.09.009.
24. Hieda A, Uemura N, Hashimoto Y, Toda I, Baba S. In vivo bioactivity of porous polyetheretherketone with a foamed surface. Dent Mater J. 2017 Mar 31;36(2):222-229. doi: 10.4012/dmj.2016-277.
25. Yang Y.-J., Tsou H.-K., Chen Y.-H., Chung C.-J., He J.-L. (2015). Enhancement of bioactivity on medical polymer surface using high power impulse magnetron sputtered titanium dioxide film. Mater. Sci. Eng. C Mater. Biol. Appl. 57 58–66. doi: 10.1016/j.msec.2015.07.039
26. Lee JH, Jang HL, Lee KM, Baek HR, Jin K, Hong KS, Noh JH, Lee HK. In vitro and in vivo evaluation of the bioactivity of hydroxyapatite-coated polyetheretherketone biocomposites created by cold spray technology. Acta Biomater. 2013 Apr;9(4):6177-87. doi: 10.1016/j.actbio.2012.11.030.
27. Kjellin P, Vikingsson L, Danielsson K, Johansson P, Wennerberg A. A nanosized zirconium phosphate coating for PEEK implants and its effect in vivo. Materialia. 2020 May 1;10:100645. doi: 10.1016/j.mtla.2020.100645.
28. Dai Y, Guo H, Chu L, He Z, Wang M, Zhang S, Shang X. Promoting osteoblasts responses in vitro and improving osteointegration in vivo through bioactive coating of nanosilicon nitride on polyetheretherketone. J Orthop Translat. 2019 Nov 21;24:198-208. doi: 10.1016/j.jot.2019.10.011.
29. Kumar N, Ramakrishnan SA, Lopez KG, Madhu S, Ramos MRD, Fuh JYH, Hallinan J, Nolan CP, Benneker LM, Vellayappan BA. Can Polyether Ether Ketone Dethrone Titanium as the Choice Implant Material for Metastatic Spine Tumor Surgery? World Neurosurg. 2021 Apr;148:94-109. doi: 10.1016/j.wneu.2021.01.059.
30. Zol SM, Alauddin MS, Said Z, et al.: Description of poly (aryl-ether-ketone) materials (PAEKs), polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) for application as a dental material: a materials science review. Polymers. 20232, 15:2170. doi: 10.3390/polym15092170.
31. Rae PJ, Brown EN, Orler EB: The mechanical properties of poly(ether-ether-ketone) (PEEK) with emphasis on the large compressive strain response. Polymer. 2007, 48:598-615. doi: 10.1016/j.polymer.2006.11.032.
32. Paszkiewicz S, Lesiak P, Walkowiak K, et al.: The Mechanical, Thermal, and Biological Properties of Materials Intended for Dental Implants: A Comparison of Three Types of Poly(aryl-ether-ketones) (PEEK and PEKK). Polymers (Basel. 2023, 8:3706. doi: 10.3390/polym15183706.
33. Sacks G, Shah V, Yao L, Yan C, Shah D, Limeta L, DeStefano V: Polyaryletherketones: Properties and applications in modern medicine. Biomedical Technology. 2024, 1:75-89. doi: 10.1016/j.bmt.2023.11.002.

34. Alqurashi H, Khurshid Z, Syed AUY, Rashid Habib S, Rokaya D, Zafar MS. Polyetherketoneketone (PEKK): An emerging biomaterial for oral implants and dental prostheses. J Adv Res. 2020 Sep 18;28:87-95. doi: 10.1016/j.jare.2020.09.004.
35. Morgan EF, Unnikrisnan GU, Hussein AI. Bone Mechanical Properties in Healthy and Diseased States. Annu Rev Biomed Eng. 2018 Jun 4;20:119-143. doi: 10.1146/annurev-bioeng-062117-121139.
36. Bhatt S, Yuan M, Galloway J, Hoffman R: Influence of molecular weight on the properties of poly(ether ether ketone). (Technical report / polymer literature). 2009-2015. doi: 10.1002/spepro.003453.
37. Korycki A, Carassus F, Tramis O, Garnier C, Djilali T, Chabert F. Polyaryletherketone Based Blends: A Review. Polymers (Basel). 2023 Sep 29;15(19):3943. doi: 10.3390/polym15193943.
38. Talbott MF: The Effects of Crystallinity on the Mechanical Properties of PEEK and Composites. J Test Eval. 1987, 15:123-131. doi: 10.1177/002199838702101104.
39. Al Lafi AG, Parker DJ, Hay JN: The crosslinking of poly (ether ether ketone): Thermally and by irradiation. Journal of Applied Polymer Science. 2015, 10:132. doi: 10.1002/app.41999
40. Chon JW, Yang X, Lee SM, et al.: Novel PEEK copolymer synthesis and biosafety—I. Polymers. 2019, 11:1803. doi: 10.3390/polym11111803
41. Yuan M, Galloway JA, Hoffman RJ, Bhatt S: Influence of molecular weight on rheological, thermal, and mechanical properties of PEEK. Polymer Engineering & Science. 2011, 51:94-102. doi: 10.1002/pen.21785.
42. Maloney A, Manaf E, Gately N, Major I, Devine DM. Annealing 3D printed PEKK: Investigating the impact of annealing on the mechanical, physical, and thermal properties in additively manufactured PEKK. Materials & Design. 2025 May 1;253:113938. doi: 10.1016/j.matdes.2025.113938.
43. Kurbanova B, Aimaganbetov K, Ospanov K, et al.: Effects of Electron Beam Irradiation on Mechanical and Tribological Properties of PEEK. Polymers (Basel. 2023, 7:1340. doi: 10.3390/polym15061340.
44. Wu J, Zeng F, Fan Z, Xuan S, Hua Z, Liu G: Hierarchical Hydrogen Bonds Endow Supramolecular Polymers with High Strength, Toughness, and Self-Healing Properties. Advanced Functional Materials. 2024, 34:2410518. doi: 10.1002/adfm.202410518
45. Yee RS, Zhang K, Ladewig BP: The Effects of Sulfonated Poly(ether ether ketone) Ion Exchange Preparation Conditions on Membrane Properties. Membranes (Basel. 2013, 13:182-95. doi: 10.3390/membranes3030182.
46. Pérez-Martín H, Buchalik-Bopp S, Guettler BE, Mackenzie P, Baidak A, Brádaigh CM, Ray D: Effect of crystallinity and morphology on the mechanical properties of CF/PEKK composites manufactured under compression moulding and automated tape placement. Materials Today Communications. 2023, 1:106442. doi: 10.1016/j.mtcomm.2023.106442.