Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 10, Issue, 02(B), pp. 30817-30821, February, 2019

ISSN: 0976-3031

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

PEEK: PROPERTIES AND APPLICATION AS DENTAL IMPLANT

Mugdha Deshpande* Nihal Devkar and Daisy Happy

Department of Periodontology, Sinhgad Dental College and Hospital, Vadgaon Budruk, Pune -411041

DOI: http://dx.doi.org/10.24327/ijrsr.2019.1002.3131

ARTICLE INFO

Article History:

Received 10th November, 2018
Received in revised form 2nd December, 2018
Accepted 26th January, 2018
Published online 28th February, 2019

Key Words:

PEEK, Implant, PEEK Implant, Implant material

ABSTRACT

The aim of this review was to describe the properties of PEEK biomaterial for its application as dental implant and review its other applications in dentistry. Literature search was carried out using PUBMED database using keywords such as PEEK, PEEK Implants, PEEK in Dentistry and papers published in English were considered. The studies relevant to our review were analysed. PEEK dental implants have less stress shielding effect compared to titanium and zirconia due to its low modulus of elasticity. PEEK also has low reactivity and low solubility than titanium. It can be reinforced by other materials to increase its bioactivity and its applications. Various applications of PEEK except dental implant have also been reviewed.

INTRODUCTION

A dental implant is a fixture placed in the alveolar bone and its function is to support the fixed or removable prosthesis. The implant is said to be oseointegrated when there is direct contact between the implant and bone surface. Osseointegration, however, depends on several variable factors such as implant material, surgical procedure, and thread geometry or design.[1] The implant material should be biocompatible, should be able to resist masticatory loads, be resistant to wear, be hydrophilic and should have appropriate surface roughness.[2]

Commercially pure grade titanium and its alloys Ti-6Al-7Nb and Ti- 6Al-4V have been used as implant material. Titanium, however, has its own disadvantages. Firstly, there is considerable hypersensitivity to titanium which may cause allergic reaction. Secondly the difference in the elastic modulus of titanium and alveolar bone decreases the stress shielding effect and may cause increased load at the implant bone interface leading to marginal bone loss. Titanium can also cause aesthetic problems because it lacks light transmission. This can cause dark shimmer of the peri implant mucosa if the biotype is thin or if there is any mucosal recession. It can pose an aesthetic problem to the patients who have high smile line. Also, patients today demand metal free prosthesis instead of having restorations made up of metal.[3]Another concern with titanium implants may be wear debris and ion leakage.[1] Dental implants made up of metal also lead to scattering of rays which are harmful for the tissues when they come in contact with irradiation.[4]

Due to all this disadvantages, consequently ceramic materials were proposed as potential surrogates. They were selected due to their high biocompatibility, good aesthetics, mechanical properties and low plaque affinity.However, it had certain disadvantages such as low temperature degradation or aging, decreased osseointegration and bone implant contact as compared to titanium. [5]Also, a recent systematic review by Haro Adanez *et al* concluded that there is no sufficient data to support clinical use of zirconia implants.[6]Furthermore, stress distribution around implant may be higher in zirconia implants than titanium as the modulus of elasticity of zirconia is higher than titanium i.e. 210 Gpa.

To avoid these adverse effects, non-metallic materials have been under development as implant biomaterials. Among them, most promising was found to be synthetic, polymeric tooth coloured material PEEK (polyetheretherketone)
Thus, this review aims to describe the properties and assess the potential of PEEK to be used as implant biomaterial.

Structural properties of PEEK

PEEK is semi crystalline aromatic polymer occurring in two phases: amorphous and crystalline phase with a melting point of 335 degree Celsius. The crystalline content may vary from 30 to 35 %. It belongs to the family of polyaryletherketone, having the chemical formula (- C6H4—O-C6H4—O- C6H4—

Corresponding author:* **Mugdha Deshpande
Department of Periodontology, Sinhgad Dental College and Hospital, Vadgaon Budruk, Pune -411041

O-) n.[3] It has excellent chemical resistance and biomechanical properties due to it structure. Thermal processing methods determine the crystalline structure of PEEK. Processing methods include injection molding and extrusion using conventional methods[7]

Physical Properties of Non-Modified Peek Are As Follows

1. Tensile strength: 97 MpA
2. Flexural strength: 170 Mpa
3. Flexural Modulus: 4.1 Gpa
4. Notched impact strength:>5 KJ/m2 [7]

It is resistant to wear and is physically and chemically stable. It is resistant to acid attacks except sulphuric acid. It remains stable and unchanged in sterilization process. It has good biocompatibility both invitro and in vivo. Their low solubility and low reactivity make it a good choice to use them in patients with history of allergies.[3,8] They flex isoelastically with bone due to which there is greater stress distribution, less stress concentration and greater stress shielding effect.[3]They are also amenable to CAD CAM process.[1] They are radiolucent and it can be helpful for MRI patients as it will lead to less artefact formation. Although PEEK has certain advantages, their bioinert nature limits its applications and its combination with the surrounding bone. Hence various strategies, surface modification methods have been developed to increase the bioactivity of the material.

Surface modifications

PEEK materials were classified depending on the size of the bioactive materials impregnated on it into two types:

Conventional PEEK composites

This includes carbonfibre-reinforcedPEEK (CFR-PEEK), glass fibre-reinforced]PEEK (GFR-PEEK), hydroxyapatite/PEEK (HA/PEEK), strontium-containing hydroxyapatite/PEEK (Sr-HA/PEEK)

Nanosized PEEK composites

This includes Nano- Ti02/PEEK, Nano-Fluorine apatite PEEK and Nano-hydroxyapatite PEEK

Carbon fibre- reinforced PEEK (CFR- PEEK)

Carbon fibres are strong, stiff and light which makes them attractive for use as reinforcement material.[9] Its modulus of elasticity is lowi.e. 18 Gpa which is almost same as cortical bone which makes them suitable for use in human bone tissue repair and implant materials.[10] CFR- PEEK stimulates osteoblast protein content without any alteration in the osteoblast morphology, thus making them choice for use as implant biomaterial.[11]According to study done by Stuart Green *et al*, the properties for CFR- PEEK are as follows depending on the concentration of carbon fibre.[7]

Table 1 Properties of CFR- PEEK

	20%	**25%**	**30%**
Tensile strength	200	209	288
Flexural strength	288	290	324
Flexural modulus	15	17	19
Notched impact strength	11	9	9.5

Glass Fibre Reinforced Peek

Glass fibre reinforcement is done to reduce the expansion rate and increase the flexure of the PEEK as they have low strength, high flexural modulus and reduced expansion rate.[12]GFR-PEEK is made up of PEEK and 10% of glass fibres with diameters ranging from microns to tens of microns.[10]Lin *et al* in 1997 had showed that GFR-PEEK can promote proliferation and differentiation of MG-63 cells.[13] Different in vitro studies have shown that it can help in formation of osteocalcin, which helps in promoting bone formation. The properties of GFR-PEEK are as follows.[12]

Table 2 Properties of GFR- PEEK

	GFR-PEEK
Tensile strength	148.2
Flexural strength	230.7
Flexural modulus	8.9

HA/PEEK

Hydroxyapatite is the main inorganic component of human bone. Khor and co-workers developed HA/PEEK composite using 40% of HA via a process of melt compounding, granulation and injection moulding. They also concluded that when the content of HA was 30%, the elastic modulus of the material was similar to cortical bone.[14] Zhang *et al* used the process of selective laser sintering to make HA composite. He also led to the revelation that this composite can promote the growth of osteoblasts and as the percentage of HA increases, the quantity of osteoblast promotion increases accordingly. [15]Ma *et al* prepared HA /PEEK composite using in situ synthetic process. According to her, this composite had favourable bonding between HA and PEEK and also had excellent mechanical properties.[8]Yu *et al* prepared composite of HA-PEEK by mixing, compaction and pressure less sintering and led to similar result that increasing the percentage of HA led to increased bone formation.[16] HA/PEEK composite had good biocompatibility, excellent mechanical strength, stress shielding effect and modulus of elasticity comparable to that of bone.[8]

Nano structured surface modifications

Spin coating with Nanohydroxyapatite

Conventional hydroxyapatite coatings are thicker which led to the development of thinner Nano hydroxyapatite coatings. Spin coating as the name suggests is the deposition of the thin layer of Nano- HA precipitated in various solventscontaining surfactants, organic solvent, an aqueous solution of Ca(NO3)2 and H3PO4 on the implants. Spinning at high speed followed by heat treatment leads to deposition of thin film.[1] Barkarmo *et al* and Johnson *et al* found out that this coating led to higher removal torques compared to uncoated dental PEEK.[17] However, the recent studies have not shown any difference between the bone implant contact of modified and unmodified PEEK

Plasma Spraying

Plasma spraying includes use of plasma torch to spray particles on the surface of implant. Hydroxyapatite or titanium can be plasma sprayed to increase the bioactivity. The plasma at high temperatures melts the particles to deposit on the surface of implant and form a rough surface. One of the disadvantages of plasma spraying is that very thick and highly rough (7micrometre) coating may get deaminated leading to failure of implant. [1] Hydroxyapatite the final HA coating has different characteristics than the initial powder.[18] As the HA coating has to be thick due to brittleness of the material, a way to modify thiscan be double coating with Ti initially to increase the adhesion and roughness and then a thin layer of HA can be incorporated to increase the bioactivity.[19]

Electron Beam Deposition

This is a coating technique which produces a dense uniform film on any substrate at low temperatures by exposing the material to beam of electrons.[20] PEEK can be coated with titanium using this method which enhances its hydrophilicity and rate of cellular proliferation. Han *et al* had showed that anodized Nano porous layer of electron beam deposited titanium can carry BMP-2, which shows accelerated bone formation.[20]Thus, a PEEK implant coated with titanium/BMP-2 can provide good clinical application in implantology. Wen *et al* evaluated the use of silicate coatings on PEEK implant via electron beam deposition method and it was seen that there was better osseointegration as well as better adhesion, osteogenesis and differentiation of mesenchymal stem cells[.21]

Plasma Immersion Ion Implantation (PIII)

Plasma immersion ion implantation includes placing a substrate in the plasma and then applying the pulse such that the ions from the plasma are implanted on the substrate. Changes induced by this treatment include crosslinking, increased young's modulus and carbonization.[22]Lu *et al* had showed that implants coated with Nano – tio2 using PIII showed some antibacterial activity against Staphylococcus aureus and E. coli.However, no studies have been carried out against periodontal pathogens which are present in vivo. Moreover, these studies are invitro and no in vivo studies have been done so far, thus this method is still under surveillance.[1]

Plasma Gas Etching

Plasma gas etching can be done with the exposure of low power plasma gases such as water vapour, oxygen, argon/ammonia. Plasma gas etching makes PEEK more hydrophilic by exposing the functional groups and producing low water contact angle on the PEEK surface.[23] It also produces Nano roughness on the surface of implant which increases its bioactivity. Invitro studies have shown that it can also lead to mesenchymal stem cell proliferation, which may be the result of increased hydrophilicity and protein adsorption.[24] Poulsson *et al* evaluated use of low-pressure oxygen plasma on surface of PEEK implants but concluded that there are no significant differences in the bone implant contact of unmodified or modified PEEK.[25] Rochford *et al* had suggested that there was increased adherence of osteoblasts even in the presence of Staphylococcus aureus on the surface of plasma gas etched PEEK implants.[26] There is no coating applied in this technique hence no risk of delamination of coating[.1]

Other surface treatment methods include acid etching with sulphuric acid, sulphonation, amination, nitration and sandblasting all of which help to increase the bioactivity of the material.[27]

PEEK as Dental Implant Material

According to Wolff's law, remodelling of bone takes place according to forces or load applied to it. Stress shielding is the reduction in the volume of bone due to loads applied on it. Lee *et al* suggested that PEEK implants showed lower levels of stresses than did the bone in direct contact with titanium or zirconia. PEEK implants were also able to withstand loads beyond static compressive strength. Increasing the strain rate can increase the yield strength in PEEK material and also its high elasticity can explain such behaviour of PEEK biomaterial.[28] However study by Sarot *et al* concluded that the titanium implant distributes the stresses in a more homogenous manner in relation to the CFR-PEEK implant due to the smaller deformation of this material.[29]Unmodified PEEK is bioinert and hydrophobic in nature. Wenz *et al* in 1990 had shown that unmodified PEEK does not have any effect on proliferation of osteoblasts [30] however Niemann *et al* in 2008 suggested that there is increase protein turnover in cells contact with unmodified and CFR-PEEK[.31] Koch *et al*(2010) had concluded through his studies that there is no difference in the osseointegration between titanium, zirconia or PEEK implants.[32]Nonetheless, the same proteomic studies have found no difference between the bio inertness of PEEK, zirconia and titanium.[2] Thus concluding from the evidence till date it can be suggested that although unmodified PEEK may have certain limitations as implant material, various surface modifications can be done to increase the bioactivity and use it as implant material.

Other Dental Applications

Peek as Implant Abutment

PEEK healing abutments can be used due to its high biocompatibility. Koutzis *et al* in his randomized clinical trial had concluded that PEEK healing abutments do not render an increased risk for marginal bone loss and soft tissue recession during the initial healing period. [33]Conversely Schwitalla in 2016 suggested that a screw made of PEEK would have to be of greater dimensions to be able to fulfil the mechanical requirements.[34] Furthermore, biofilm formation on the surface of PEEK is equal or lower than on the surface of conventionally applied abutment materials such as zirconia and titanium.[35] Also the reduced difference in the elastic modulus of bone and PEEK reduces stress shielding effects and encourages new bone formation. Thus, owing to all these properties PEEK could be considered as alternative to titanium as implant abutment material.

PEEK as Removable prosthesis Material

Dentures can be constructed with PEEK using CAD/CAM technology. According to Tannous *et al*, PEEK clasps offer a lower retentive force than metal clasps; however, properly designed PEEK clasps with an undercut of 0.5 mm could provide adequate retention for clinical use.[36]According to Whitty *et al* the advantages of using PEEK as partial denture framework are its strong and light weight, taste neutrality, no thermal or electrical conductivity, non-allergic, highly resistant to abrasion and decay and acts as shock absorbent while chewing.[37]Another application of PEEK could be in the construction of removable obturator.[1]

PEEK Crowns

Recent publications have reported that PEEK is suitable material for double crown system. Many surface conditioning methods are adopted to increase the bonding with resin composite crowns. Air abrasion and without silica coatings creates wettable surface but etching with sulphuric acid creates rough and chemically processed surface.[38] Hallman *et al* showed that abraded PEEK surface with 50 µm alumina particles followed by etching with piranha solution lead to the highest tensile bond strength when Heliobond was used as adhesive.[39]Stock *et al* in her study suggested that —in contrast to metal double crowns—

PEEK was easier to process, which facilitated especially the adaption process. In addition, PEEK was more flexible than metal but more difficult to polish.[40]Uhrenbacher in his study however concluded that PEEK crowns showed significantly lower tensile strength than zirconia crowns. [41]Thus these studies suggest that PEEK can be used either as coping to composite or the bonding to PEEK must be improved by variable methods to use it for fabrication of crowns.

Peek fixed Partial Dentures

PEEK has high strength to weight ratio, elastic properties similar to human bone, zero corrosion rate, and extremely low water absorption which makes it suitable material for fabrication of fixed partial dentures.[42]CAD-CAM designed composites and polymethylmethacrylate (PMMA) fixed dentures have superior mechanical properties compared to conventional fixed dentures .[1] Starwarcyzk *et al* suggested that the FPD fabricated with PEEK using CAD CAM technology has high fracture resistance than pressed granular or pellet shaped PEEK dentures.[43]However, no clinical studies have compared abrasion produced on teeth by PEEK and other biomaterials. Hence no conclusion can be made regarding use of PEEK as a substrate for FPD. However, owing to its mechanical properties and good abrasion resistance, future studies may warrant the use of PEEK as material for FPD.

CONCLUSION

This articlereviews various properties of PEEK material, its applicability as implant material and its other applications in dentistry. The only disadvantage of PEEK is its bioinert nature which can be made bioactive by various surface modification methods mentioned in the review. PEEK can thus be used as an alternative implant material to titanium following certain changes that improves the property of the material. Owing to its good mechanical properties, excellent biocompatibility and low modulus of elasticity PEEK also holds a promise in future for applications in dentistry other than implants, although current evidence doesn't strongly support its use in each aspect of dentistry

References

1. Najeeb S *et al*. Nanomodified Peek Dental Implants: Bioactive Composites and Surface Modification—A Review. Int J Dent 2015;1-7
2. Harsha L and Anand S. Literature Review on "Peek" Dental Implants. *Research J Pharm and Tech* 2016: 9(10);1797-1801
3. Verma A. Novel innovations in dental implant biomaterials science: Zirconia and PEEK polymers. *Int J Appl Dent Sci* 2018; 4(4): 25-29.
4. Mishra S and Chowdhary R. PEEK materials as an alternative to titanium in dental implants: A systematic review. Clin Implant Dent Relat Res 2018;1–15.
5. Cionca N, Hashim D, Mombelli A. Zirconia dental implants: where are we now, and where are we heading? Periodontol 2000 2017:73;241-58.
6. Adanez M, Nishihara H, Att W. A systematic review and meta-analysis on the clinical outcome of zirconia implant–restoration complex. *J Prosthodont Res* 2018:62(4);397-406.
7. Green S and Schelgel J. A Polyaryletherketone Biomaterial for use in Medical Implant Applications. Proceedings of a Conference held in Brussels 2001:1-7.
8. Ma R and Tang T. Current Strategies to Improve the Bioactivity of PEEK. Int J Mol Sci 2014: 15; 5426-5445.
9. Bishop S. The mechanical performance and impact behaviour of carbon-fibre reinforced PEEK. Composite Structures 1985:3(4);295-318.
10. Song X and Liu C. The mechanical performance and impact behaviour of carbon-fibre reinforced PEEK. *J Simul* 2017:5(1)
11. Morrison C, Macnair R, Macdonald C *et al*. In vitro, biocompatibility testing of polymers for orthopaedic implants using cultured fibroblasts and osteoblasts. Biomaterials 1995;16(13):987-92.
12. E.Z. Li *et al*. Research on Tribological Behaviour of PEEK and Glass Fibre Reinforced PEEK Composite Physics Procedia 50 2013: 453 – 460.
13. Lin T W, Corvelli A A, Frondoza C G *et al*. Glass peek composite promotes proliferation and osteocalcin production of human osteoblastic cells. Journal of Biomedical Materials Research 1997;36(2):137–144.
14. Bakar M S A, Cheang P, Khor K A. Tensile properties and microstructural analysis of spheroidized hydroxyapatite–poly (etheretherketone) bio composites. Materials Science & Engineering A 2003 :345(1–2);55-63.
15. Zhang Y, L. Hao, M. M. Savalani, *et al*. In vitro, biocompatibility of hydroxyapatite-reinforced polymeric composites manufactured by selective laser sintering. *J Biomed Mater Res A* 2009; 91A (4):1018–1027.
16. Yu S, Hariram K P, Kumar R, *et al*. In vitro apatite formation and its growth kinetics on hydroxyapatite/ polyetheretherketone bio composites. Biomaterials 2005;26(15):2343-2352.
17. Barkarmo S *et al*. Nano-hydroxyapatite-coated PEEK implants: a pilot study in rabbit bone. *J Biomed Mater Res A* 2012;101(2):465-71.
18. Y.C. Tsui, C. Doyle, T.W. Clyne, Plasma sprayed hydroxyapatite coatings on titanium substrates. Part 1: Mechanical properties and residual stress levels, Biomaterials 1998;19(22).
19. P. Robotti, G. Zappini, Metal and HA coating technologies for PEEK implants, in: Proceedings, MD&M conference, Minneapolis, Minnesota, USA, October 12- 14, 2010
20. Han C *et al*. The electron beam deposition of titanium on polyetheretherketone (PEEK) and the resulting enhanced

biological properties. Biomaterials 2010; (31): 3465–3470
21. Wen J *et al*. In Vitro and in Vivo Evaluation of Silicate-Coated Polyetheretherketone Fabricated by Electron Beam Evaporation. ACS Appl Mater Interfaces 2016;8(21):13197-13206.
22. Wakelin E *et al*. Bio-Activation of Polyether Ether Ketone Using Plasma Immersion Ion Implantation: A Kinetic Model. J Biomater Sci Polym Ed 2018; 5:520-542.
23. C-M. Chan, T.-M. Ko, and H. Hiraoka. Polymer surface modification by plasmas and photons. Surface Science Reports 1996; 24(1-2): 1–54.
24. J. Waser-Althaus, A. Salamon, M. Waser *et al*. Differentiation of human mesenchymal stem cells on plasma-treated polyetheretherketone. Journal of Materials Science Materials in Medicine 2014;25(2):515–525
25. A. H. C. Poulsson, D. Eglin, S. Zeiter *et al*. Osseointegration of machined, injection moulded and oxygen plasma modified PEEK implants in a sheep model. Biomaterials 2014; 35 (12): 3717–3728.
26. E. T. J. Rochford *et al*. An in vitro investigation of bacteria-osteoblast competition on oxygen plasma-modified PEEK. J Biomed Mater Res A 2014;102(12): 4427–4434.
27. Rahmitasari F *et al*. PEEK with Reinforced Materials and Modifications for Dental Implant Applications. *Dent J* 2017;5(35):1-8.
28. Lee *et al*. Stress shielding and fatigue limits of poly ether ether ketone dental implants. *J Biomed Mater Res Part B* 2012;100: 1044-1052.
29. Sarot JR *et al*. Evaluation of the stress distribution in cfr-PEEK dental implants by the three-dimensional finite element method. *J Mater Sci Mater Med* 2010; 21:2079–85
30. Wenz *et al*. In vitro biocompatibility of polyetheretherketone and polysulfone composites. *J Biomed Mater Res* 1990; 24:207–15.
31. Nieminen T *et al*. Amorphous and crystalline polyetheretherketone: mechanical properties and tissue reactions during a 3-year follow-up. *J biomed Mater Res Part A* 2008; 84:377–83.
32. Koch F *et al*. Osseointegration of one-piece zirconia implants compared with a titanium implant of identical design: A Histomorphometric study in the dog. Clin Oral Implants Res 2010; 21:350–6.
33. Koutouzis T, Richardson J, Lundgren T. Comparative soft and hard tissue responses to titanium and polymer healing abutments. J Oral Implantol 2011; 37:174–82.
34. Andreas Dominik Schwitalla, Tobias Spintig, Ilona Kallage and Wolf-Dieter Müller, Pressure behaviour of different PEEK materials for dental implants, J Mech Behav Biomed Mater 2016;0:0
35. Hahnel S *et al*. Biofilm formation on the surface of modern implant abutment materials. Clin Oral Impl Res 2014; 0:1–5
36. Tannous F, Steiner M, Shahin R, Kern M. Retentive forces and fatigue resistance of thermoplastic resin clasps. Dental Mater 2012; 28:273–8.
37. Whitty T. PEEK – A New Material for CAD/CAM Dentistry. Juvora Dental Innovations 2014
38. G Skirbutis *et al*. A review of PEEK polymer's properties and its use in prosthodontics. Stomatologija2017;19:19-23.
39. Hallmann L, Mehl A, Sereno N, Hämmerle CH. The improvement of adhesive properties of PEEK through different pre-treatments. Appl Surf Sci 2012;258;7213-8.
40. Stock V *et al*. PEEK Primary Crowns with Cobalt-Chromium, Zirconia and Galvanic Secondary Crowns with Different Tapers—A Comparison of Retention Forces. Materials (Basel) 2016;9(3):187
41. Uhrenbacher J *et al*. The effect of surface modification on the retention strength of polyetheretherketone crown adhesively bonded to dentin abutments. *J Prosthet Dent* 2014; 112:1489-97.
42. Sinha N, Gupta N, Reddy K M, Shastry Y M. Versatility of PEEK as a fixed partial denture framework. *J Indian Prosthodont Soc* 2017; 17:80-3.
43. Starwarcyzk B *et al*. Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. *Dent Mater J* 2015; 34:7-12.

How to cite this article:

Mugdha Deshpande Nihal Devkar and Daisy Happy,.2019, Peek: Properties and Application As Dental Implant. *Int J Recent Sci Res.* 10(02), pp. 30817-30821. DOI: http://dx.doi.org/10.24327/ijrsr.2019.1002.3131

****