



## Review Article

## Polyetheretherketone (PEEK) and its application in prosthodontics: A review

Pratul Kumar Agrawal<sup>1,\*</sup>, T Ashish<sup>2</sup>, Kavya Patali S<sup>1</sup><sup>1</sup>Dept. of Prosthodontics, Vokkaligara Sangha Dental College and Hospital, Bengaluru, Karnataka, India<sup>2</sup>A B Shetty Memorial Institute of Dental Sciences, Mengaluru, Karnataka, India

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## ABSTRACT

Introduction of metal-free restoration has always been a hot topic of research in the field of dentistry. Polyetheretherketone (PEEK), a polymer that is metal-free and with the similarity of modulus of elasticity with bone and dentin makes it a suitable material. In the past 2-3 years, it has gained a lot of popularity in prosthodontics however it has not been studied in depth. So the purpose of this review is to summarize the outcome of the various research conducted on this material so as to undervolve the following sequencerstand it in a better way and to popularize its use in clinical application.

**Key Messages:** Polyetheretherketone (PEEK), with the similarity of modulus of elasticity with bone and dentin makes it a suitable material in prosthodontics.

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## 1. Introduction

Polyetheretherketone (PEEK) is a synthetic, semi-crystalline, tooth-colored and high temperature thermoplastic polymer of the family of polyaryletherketone (PAEK). It consists of a linear aromatic backbone molecular chain interconnected by ketone and ether functional groups (Figure 1).

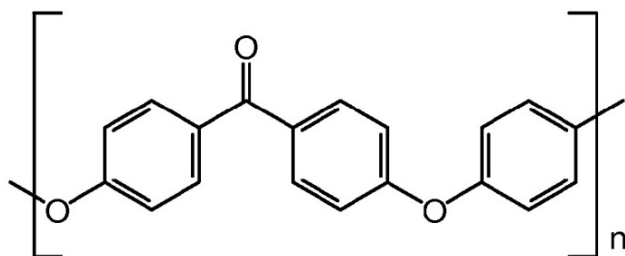


Fig. 1:

Historically, it was first developed by UK based Imperial Chemical Industries (ICI) in association with Victrex PLC in 1978. In 1981, PEEK along with its composite material like glass and carbon filled products were commercialized for industrial applications such as aircraft and turbine blades.<sup>1-4</sup> By the late 1990s, PEEK gained popularity in orthopedic and traumatic applications and started replacing metal implant components.<sup>5</sup> PEEK was commonly used as a material of interbody fusion cage in the vertebral surgery.<sup>6</sup> With the development of carbon fiber reinforced PEEK (CF/PEEK), this new composite material was mainly used for fracture fixation and femoral prosthesis in artificial hip joints.<sup>7</sup> In 2012, JUVORA™ was launched to serve the denture market.<sup>2</sup> Over the past few years, PEEK and its composites have attracted a great deal of interest in the field of dentistry because of its various beneficial properties.

Titanium (Ti) and its alloys are broadly used as dental and orthopedic implant materials because of high corrosion resistance, biocompatibility, re-passivation, and adequate mechanical properties.<sup>8</sup> The corrosion resistance of Ti and its alloys is a result of the formation of oxide films (TiO<sub>2</sub>) when comes in contact with oxygen. However, the conditions, such as cyclic loading, implant micromotion,

\* Corresponding author.

E-mail address: [pratul2407@gmail.com](mailto:pratul2407@gmail.com) (P. K. Agrawal).

acidic environments, and their combined effects, can result in the permanent breakdown of these oxide film which may lead to exposure of the bulk metal to an electrolyte and thereby corrosion happens pathophysiologically. Due to this event, Ti releases ions and triggers an immune reaction (Type IV) that is potentially directed towards the implant and thereby osteolysis.<sup>9</sup> Moreover, the titanium and its alloys have an elastic modulus (102-110GPa) which is significantly higher than bone (14GPa) and resulting in severe stress-shielding on the peri-implant bones, which will lead to adsorption of adjacent bone tissues and cause prosthetic loosening and failure. Also, the metallic implants cause scattering rays in the field of radiation and its radiopacity causes artifacts in computed tomography (CT) images and limit the ability to examine the patient with magnetic resonance imaging (MRI).<sup>10,11</sup>

During the last two decades, efforts are being made to develop metal-free implants, abutments, and restorative materials. One such example is zirconium dioxide. Unfortunately, low- temperature degradation and high Young's modulus (210 GPa) are potential disadvantages of this material.<sup>12,13</sup>

Polymers such as ultra-high molecular weight polyethylene (UHMWPE), polytetrafluoroethylene (PTFE), polymethyl methacrylate (PMMA), polylactide (PLA), polyglycolide (PGA) and polyhydroxybutyrate (PHB) were widely used in various biomedical applications. But they tend to be too flexible and too weak to meet the mechanical demands as orthopedic implants. Besides, they absorb liquids and swell, leach undesirable products and also get affected by sterilization process.<sup>14</sup>

For these stated demerits of Ti and its alloys, zirconium dioxide and other different polymers, high-performance polymers (HPP) are being proposed as implant materials in medicine of whom the most commonly used HPP is polyetheretherketone (PEEK).<sup>15</sup>

The major beneficial property of using PEEK as a dental material is its lower Young's (elastic) modulus (3-4GPa) being close to the human bone(14GPa) and dentin(15GPa). This provides lesser stress shielding when compared to titanium which used as an implant material. PEEK can also be modified easily by the incorporation of other materials. For example; incorporation of carbon fibers can increase the elastic modulus up to 18GPa which is closer to cortical bone and dentin. Moreover, tensile properties of PEEK are analogous to those of bone, and dentin, making it a suitable restorative material as far as the mechanical properties are concerned.<sup>16</sup>

PEEK is bio-inert and hydrophobic in nature so there are a number of methods that have been proposed to improve the bioactivity of PEEK including physical and chemical surface modifications, surface coating with synthetic osteoconductive hydroxyl apatite and incorporating bioactive particles.<sup>16</sup>

PEEK has a grayish-brown color so using it in the esthetic region is a point of concern so usually veneering with composite or acrylic resin is required which itself is having a complex process.

PEEK other than in implant and fixed prosthesis has been used so far as a provisional abutment for the implant, implant-supported bars, fixed dental prosthesis as a crown or bridge or interim resin bonded, removable prosthesis as a clamp material and as a craniofacial prosthetic material.<sup>17</sup>

The purpose of this review is to highlight the various properties, manufacturing process and the application of PEEK so that to understand it in a better way and thereby to be applied in various clinical practices.

## 2. Synthesis of PEEK

The monomer unit of etheretherketone polymerizes via step-growth dialkylation reaction of bis-phenolate salts to form polyetheretherketone. 4,4'-difluorobenzophenone reacts with the disodium salt of hydroquinone in a polar solvent of diphenyl sulphone at 300°C to synthesize PEEK (Figure 2).<sup>16</sup>

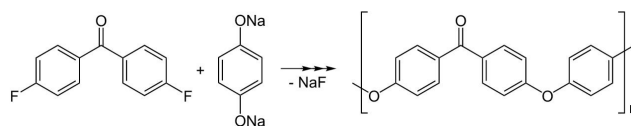


Fig. 2:

## 3. Manufacturing Method of PEEK

Polyetheretherketone is supplied as granules, as a powder or as a fine powder form (Figure 3). PEEK appears amber-colored in the melt and grayish in its solid crystalline state (natural colors). The most important polymer processing operations are:<sup>18</sup>

1. Extrusion and
2. Injection moulding.

Both these processes involve the following sequence of steps:

- (a) Heating and melting the polymer,
- (b) Pumping the polymer to the shaping unit,
- (c) Forming the melt into the required shape and dimensions and
- (d) Cooling and solidification.

Other processing methods include compression moulding, calendering, blow moulding, thermoforming, and rotational moulding.

Three forms of PEEK have been used so far for the fabrication of fixed prosthesis which is (Figure 4):<sup>19,20</sup>

- (a) Pressing from granules (PPG)
- (b) Pressing from pellets (PPP), and
- (c) PEEK Blanks for milling (PM)



Fig. 3:

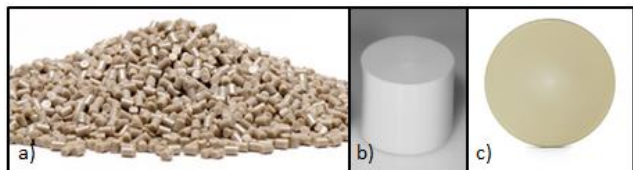


Fig. 4:

#### 4. Properties of PEEK

1. The mechanical properties of PEEK are close to that of human cortical bone and dentin. So PEEK has less stress shielding effect [Tables 1 and 2].<sup>3,16</sup>
2. PEEK maintains its electrical properties up to temperature 200°C.<sup>1</sup>
3. The aryl rings of PEEK are interconnected via ketone and ether groups located at opposite ends of the ring (as the “para” position). The resonance stabilized chemical structure of PEEK results in delocalization of higher orbital electrons along the entire macromolecule, making it extremely unreactive and inherently resistant to chemical, thermal, and post-irradiation degradation.<sup>5</sup>
4. PEEK is chemical resistant apart from concentrated sulfuric acid which dissolves it and liquid bromine and fuming nitric acid which degrades the PEEK.<sup>1,5</sup>
5. In thermal properties, PEEK has a high glass transition temperature of 143°C and a melting temperature of 334°C. Naturally, PEEK is non-flammable and having very minute combustion products of CO<sub>2</sub> and CO.<sup>1</sup>
6. PEEK can be sterilized and irradiated due to its stability at temperatures above 300°C.<sup>21</sup> The irradiated PEEK products can easily be decontaminated by conventional washing procedures like dilute acids and detergents.<sup>1</sup>
7. PEEK exhibit good biocompatibility in vitro and in vivo, causing neither toxic or mutagenic effects nor clinically significant inflammation.<sup>22-28</sup>
8. PEEK is bio-inert but its bioactivity can be increased by surface modification and composite preparation.<sup>29-70</sup>
9. PEEK is radiolucent so it will not interfere with postoperative and prognostic radiographic imaging modalities.<sup>3</sup> However barium sulfate, a radio-opacifier, may be added to PEEK to improve visualization and contrast in imaging in case of trauma surgery.<sup>14</sup>

10. PEEK is wear resistant<sup>11,71-73</sup> and different materials can be added to increase its wear resistance like graphitic carbon nitride (g-C<sub>3</sub>N<sub>4</sub>).<sup>74</sup>
11. PEEK has a water solubility of 0.5 w/w%, and it is not chemically damaged by long-term water exposure, even at temperatures of up to 260°C.<sup>75,76</sup>
12. PEEK has better color stability than PMMA and composite resin.
13. PEEK can be made anti-microbial to different common oral pathogens like *S. mutans*, *S. aureus*, *Fusobacterium nucleatum*, *Porphyromonas gingivalis*, and *E.coli* by using various methods like the incorporation of ZnO, multilevel TiO<sub>2</sub> nanostructured, treatment with Nitrogen Plasma Immersion Ion Implantation, Fluorination, Impregnation of Silver(Ag+) ions on Hydroxyapatite coated PEEK and lactam treatment.<sup>77-82</sup>
14. PEEK has low translucency and greyish in color so composite veneering is required for esthetic purpose.<sup>83</sup>

**Table 1:** Physical and mechanical properties of non-reinforced PEEK<sup>3</sup>

|                                 |                        |
|---------------------------------|------------------------|
| Density                         | 1.32 g/cm <sup>3</sup> |
| Young's Modulus (E)             | 3700 MPa               |
| Tensile Strength ( $\sigma_t$ ) | 100 MPa                |
| Elongation(%)                   | 50-150                 |
| Notch Test                      | 55 kJ/m <sup>2</sup>   |
| Glass Temperature               | 143°C                  |
| Melting Point                   | 334°C                  |
| Thermal Conductivity            | 0.25 W/m.K             |
| Water sorption(23°C)[%]         | 0.15-0.44              |

**Table 2:** Tensile strength and Young's modulus of PEEK, CFR-PEEK, PMMA and mineralized human tissues<sup>15</sup>

| Material      | Tensile Strength(MPa) | Young's Modulus(GPa) |
|---------------|-----------------------|----------------------|
| PEEK*         | 80                    | 3-4                  |
| CFR-PEEK*     | 120                   | 18                   |
| PMMA*         | 48-76                 | 3-5                  |
| Cortical Bone | 104-121               | 14                   |
| Dentin        | 104                   | 15                   |
| Enamel        | 47.5                  | 40-83                |
| Titanium      | 954-976               | 102-110              |

\*-PEEK, Polyetheretherketone; CFR-PEEK, Carbon reinforced polyetheretherketone; PMMA, Polymethylmethacrylate

#### 5. Application of PEEK

Due to the various mention properties, PEEK is a promising material for dental use and have been applied in the various field of prosthodontics (Figure 5).

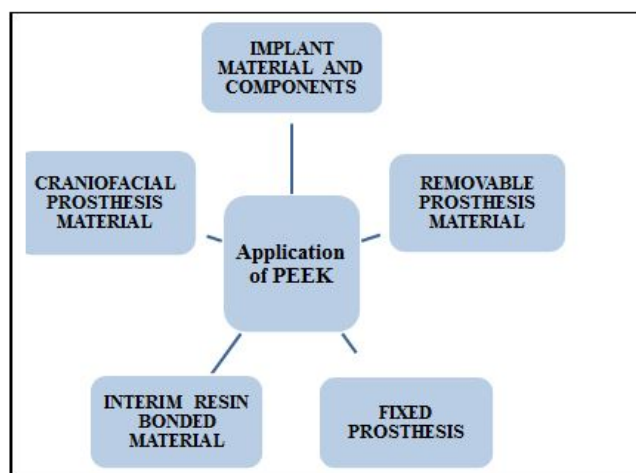


Fig. 5:

## 6. PEEK as an Implant Material and Components

### 6.1. PEEK as an implant material

The introduction of dental implants has increased the quality of life for many patients with tooth loss. Implants based on titanium and titanium alloys, such as Ti-6Al-7Nb and Ti-6Al-4V, are most commonly used however their use has led to problems like hypersensitivity to titanium, stress shielding effect due to gradient difference in the elastic moduli of a titanium implant and its surrounding bone, esthetic problems due to its lack of light transmission which can provoke a dark shimmer of the peri-implant soft tissue in cases of thin biotype mucosa and/or mucosa recession around the titanium implant, increase in the number of patients preferring more of dental reconstructions with metal-free materials.<sup>15,84</sup>

All-Ceramic like Zirconia is a better suitable alternative because of its tooth-like color, mechanical properties, biocompatibility, and low plaque affinity. But a systematic review of the literature by Andreiotelli et al. concludes that the scientific clinical data are not sufficient to recommend ceramic implants to be used routinely.<sup>82</sup> Also, the elastic modulus of the zirconia implant (210 GPa) is higher than the titanium implant which generates even higher stress peaks around the surrounding bone than titanium.<sup>85</sup>

PEEK is a biocompatible material with an elastic modulus of 3.6 GPa, which is closer to that of bone and its fiber reinforced PEEK has a similar elastic modulus of 18 GPa to that of cortical bone. So it has a less stress shielding effect than titanium.

A 3-dimensional study done by Sarot et al. found no significant advantage of CFR-PEEK implant over titanium implant.<sup>86</sup> However other studies have evaluated the fatigue limits of different PEEK implants and found that fiber-reinforced PEEK can tolerate the maximum masticatory forces both in the anterior and posterior region.<sup>87-89</sup> In a

case report presented by Marya et al., a single PEEK implant was placed at the region of 46 which showed adequate stability with the minimal bone loss after a follow-up period of six months.<sup>90</sup>

Unmodified PEEK is hydrophobic (water-contact angle of 80–90°) and bio-inert in nature so to improve the bioactivity of PEEK two methods have been developed which includes A) surface modification and B) composite preparation (Figure 6).<sup>11</sup>

#### 6.1.1. Surface modification

It can be done by a) physical treatment, b) chemical treatments or c) surface coating. The commonly used physical treatments are plasma modifications such as ammonia/argon (NH<sub>4</sub>/Ar) plasma,<sup>29</sup> hydrogen/argon (H<sub>2</sub>/Ar) plasma,<sup>29</sup> methane and oxygen (CH<sub>4</sub>/O<sub>2</sub>) plasma,<sup>30</sup> nitrogen and oxygen (N<sub>2</sub>/O<sub>2</sub>) plasma,<sup>31</sup> ammonia (NH<sub>4</sub>) plasma, oxygen and argon (O<sub>2</sub>/Ar) plasma,<sup>32</sup> Accelerated Neutral Atom Beam (ANAB),<sup>33</sup> and oxygen(O<sub>2</sub>) plasma.<sup>34</sup> In the chemical treatments, only wet chemistry modification<sup>35,36</sup> or sulfonation treatment<sup>37</sup> can chemically modify the surface of PEEK. Bioactivity of PEEK can also be increased by a surface coating of hydroxyapatite (HA), titanium (Ti), gold, titanium dioxide (TiO<sub>2</sub>), diamond-like carbon (DLC) or tert-butoxides using various methods, including cold spray technique,<sup>38</sup> spin coating techniques,<sup>39</sup> Aerosol Deposition (AD),<sup>40</sup> Radio-frequency (RF) magnetron sputtering,<sup>41</sup> Plasma Immersion Ion Implantation and Deposition (PIII&D),<sup>42</sup> Ionic Plasma Deposition (IPD),<sup>43</sup> Vacuum Plasma Spraying (VPS),<sup>44</sup> Physical Vapor Deposition (PVD),<sup>45</sup> Arc Ion Plating (AIP),<sup>46-48</sup> and electron beam deposition.<sup>49</sup> Surface treatment alone or in combination with surface coating can greatly improve the bioactivity of PEEK.

#### 6.1.2. Composite preparation

Hydroxyapatite(HA), tricalcium phosphate(TCP), calcium silicate (CS), bioglass, and glass fibers are known as bioactive materials due to their ability to spontaneously bond to living bone and as PEEK is inert in nature, their bonding characteristics can be increased by impregnating PEEK with these bioactive materials. The PEEK composites were classified into two kinds by the size of the impregnating bioactive materials:

1. Conventional PEEK composites(>100nm) and
2. Nano-sized (<100 nm) PEEK composites

#### 6.1.3. Conventional PEEK composites

Several studies have been reported which have used the conventional PEEK composites to increase the bioactivity.<sup>50-64</sup>

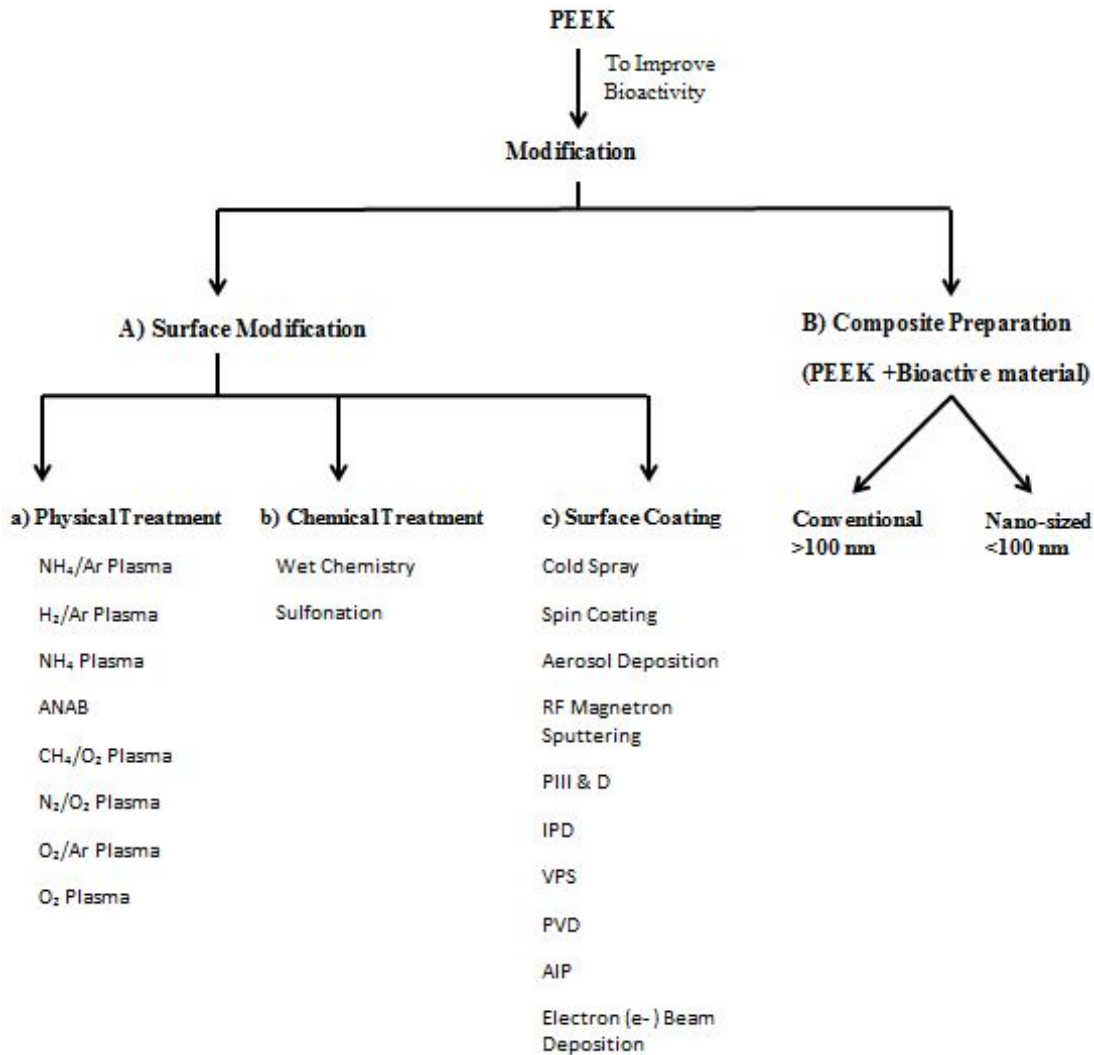


Fig. 6:

#### 6.1.4. Nano-sized PEEK composites

Conventional HA/PEEK composite may not bear long-term critical loading due to debonding between HA filler and PEEK matrix because of the negative impact on the mechanical properties of PEEK. This can be overcome by using nano-sized particles instead of larger particles. Many studies have reported better bioactivity and mechanical properties with nano-sized PEEK Composites.<sup>65-70</sup>

#### 6.2. PEEK as implant abutment

In cases of screw-retained implant-supported reconstructions of PEEK, an abutment screw made of PEEK might be advantageous over a conventional metal screw due to its similar elasticity. According to Juvora (Juvora Ltd., Thornton Cleveleys, Lancashire, United Kingdom), a manufacturer of PEEK, the abutment screw

should be tightened to a torque of 15 Ncm as above this plastic deformation of mesostructure of PEEK occurs which generally happens in cases of Ti6Al4V alloy with high rigidity (Young's Modulus: 120 GPa). Also, in the case of failure of the PEEK abutment screw the fragment remaining in the implant would be easier to remove. A study done by Schwitalla et al had reported that PEEK reinforced by >50% continuous carbon fibers would be the material of choice for PEEK abutment screws. However long clinical studies are required to use it as a material of choice as an abutment screw.<sup>91</sup>

#### 7. PEEK as Removable Prosthesis Material

Removable dental prostheses (RDP) are mostly fabricated with chrome-cobalt frameworks however the esthetically unacceptable display of metal clasps, the increased weight

of the prosthesis, the potential for metallic taste, and allergic reactions to metals led to the introduction of a number of other non-metallic materials in which PEEK is one of them. Modified poly-ether-ether-ketone [PEEK] material containing 20% ceramic fillers (BioHPP; Bredent GmbH, Senden, Germany) have shown better esthetics, good biocompatibility, better mechanical properties, high-temperature resistance, and chemical stability.<sup>92</sup>

## 8. PEEK as Fixed Prosthesis

PEEK blanks have a grayish-brown or pearl-white opaque color which makes it unsuitable for esthetic dental restorations, especially for the anterior region. Thus, veneering is required which can be done either by composite resin or acrylic resin. However, the bond strength of the material is low when combined with composite resin because of the inert chemical performance, low surface energy, and surface modification resistance of PEEK. Thus, improving the surface properties of PEEK has become a research hotspot. Adhesive properties are generally influenced by the surface pre-treatment and luting cement. Several studies have investigated the bonding characteristics of PEEK and veneering resins. Some studies have reported better bond strength of resin cement with PEEK after preconditioning with air abrasion and then conditioning with Visio-link.<sup>83,93</sup> In another studies surface pretreatment using sulfuric acid has shown improved bond strength with veneering resin materials.<sup>94,95</sup> Few studies also assessed the bond strength of resin cement after etching with piranha solution.<sup>96,97</sup> These studies, however, reported conflicting results. While one study observed no effect of piranha acid etching on the bond properties,<sup>96</sup> other studies reported higher bond strength when applying an adhesive on airborne-particle-abraded and piranha etched PEEK compared to etching alone.<sup>97</sup> One study showed that methylmethacrylate (MMA)-based adhesive materials were able to establish an adequate bonding to PEEK etching and adhesive system.<sup>94</sup>

Poor wetting ability of PEEK is the main problem of achieving adequate bond strengths between the PEEK and the composite resin. To date, airborne-particle abrasion and etching still represent good methods of improving the wettability of PEEK. Some studies have evaluated the bond strength of PEEK with dental tissues and found better bonding using different pre-treatment and conditioning method with resin cement.<sup>98,99</sup>

Bond strength of PEEK substrate with veneering materials or dentin after various pre-treatment and conditioning is summarized in (Table 3).

### 8.1. PEEK as FDP framework

FDPs created with CAD/CAM have shown lower deformation and higher fracture load than pressed ones.

They had even higher fracture load than other different materials as mentioned in (Table 4).<sup>100</sup>

A clinical report was presented by Zoidis et al, where a modified polyetheretherketone (PEEK) implant framework material in combination with prefabricated high-impact poly(methyl methacrylate) (PMMA) veneers was used as an alternative material for the fabrication of a complete maxillary arch implant-supported fixed restoration and after two years of clinical follow-up there was no sign of screw loosening, veneering material chipping, wear, or staining.<sup>101</sup>

### 8.2. PEEK as single crown FDP

A clinical report presented by Zoidis et al, where a maxillary right second molar was restored with PEEK crown with a veneering of composite resin and there was no complication reported after 22 months of follow-up. Therefore, PEEK can be suggested as a material for FDPs but still long term clinical studies are required.<sup>102</sup>

### 8.3. Polishing of PEEK

Any adjustment with the fixed prosthesis can lead to an increase in surface roughness and thereby bacterial plaque accumulation. Polishing should result in lower surface roughness (SR) of < 0.2mm with low surface free energy (SFE) which can be done by using different polishing devices. A study done by Sturz et al. had reported avoiding the use of air polishing procedures for polishing PEEK as it leads to an increase in surface roughness.<sup>103</sup> In another study done by Heimer et al reported the use of 3-body abrasion system (consisting of polishing pastes such as aluminum oxide or diamond particles) than 2-body abrasion (including grinding burs and both bonded and coated abrasives).<sup>104</sup>

## 9. PEEK as Interim Resin Bonded Fixed Prosthesis

Resin-bonded fixed dental prosthesis (RBFDPs) is a conservative treatment for tooth replacement in the esthetic zone of which metal-ceramic RBFDPs is most commonly used. However, the high rate of de-bonding, un-esthetic display of gray color of the incisal third of teeth led to the introduction of other materials to improve esthetics. A modified PEEK-based polymer with 20% ceramic fillers (BioHPP, Bredent GmbH, Senden, Germany) have been used for interim bases which provided clinically good result without any complication.<sup>105,106</sup>

**Table 3:** Bond strength of PEEK substrate with veneering material or dentin after various pre-treatment and conditioning

| S.No | Pre-treatment<br>(Pre conditioning)   | Adhesive System<br>(Conditioning)   | Veneering resin                                    | Conclusion   | References |
|------|---|---|--|--|------------|
| 1.   | Air abraded with 50 $\mu$ m alumina   | i. Z Prime Plus<br><br>ii. Ambarino P60<br>iii. Monobond Plus<br>iv. Visio-link<br>v. Signum PEEK                           | i. Sinfony<br><br>ii. GC Gradia<br>iii. Vita VM LC | Visio-link and Signum PEEK bond showed highest bond strength   | 83         |
| 2.   | i. Acid etching with 98% sulfuric acid for 1 min,<br><br>ii. Sandblasting for 10 sec with 50 $\mu$ m alumina,<br><br>iii. Sandblasting for 10 sec with 110 $\mu$ m alumina,<br>iv. Rocatec sytem  | i. Rely X Unicem,<br><br>ii. Helibond and Tetric hybrid composite   | Acrylic Hollow Cylinder                            | Better bond strength with etched surface specimen and adhesive system  | 94         |
| 3.   | i. 98% sulfuric acid<br><br>ii. 9.5% hydrofluoric acid<br>iii. Argon plasma treatment<br>iv. Sandblasting with 50 $\mu$ m alumina   | i. Rely X <sup>TM</sup> Unicem<br><br>ii. SE Bond/Clearfil AP-X   |  | 98% sulfuric acid and argon plasma treatments improved the bond strength of PEEK composites with resin cement  | 95         |
| 4.   | i. Air abrasion with 50 $\mu$ mAl <sub>2</sub> O <sub>3</sub> (0.05MPa),<br><br>ii. 50 $\mu$ mAl <sub>2</sub> O <sub>3</sub> (0.35MPa)<br>iii. 110 $\mu$ mAl <sub>2</sub> O <sub>3</sub> (0.05MPa)<br>iv. 110 $\mu$ mAl <sub>2</sub> O <sub>3</sub> (0.35MPa)<br>v. Rocatec | i. Visio link(VL),<br><br>ii. Monobond plus/Heliobond(MH)<br>iii. Scotchbond Universal(SU),<br>iv. Dialog Bonding Fluid(DB) | Dialog Occlusal composite                          | Highest tensile bond strength was achieved by conditioning with visio-link in combination with the pretreatment of airborne particle abrasion at a pressure of 0.35 MPa. | 93         |
| 5.   | i. Etching with 98% sulfuric acid for 30 sec  | i. Visio-link   | i. Sinfony   | Etching did not had any effect on the bond strength however conditioning had significantly improved the bond strength  | 96         |

Continued on next page

Table 3 continued

|    |   |                             |  |   |    |
|----|---|-----------------------------|--|---|----|
|    | ii. Etching with piranha solution for 30 sec    | ii. Signum PEEK Bond        | ii. Vita VM LC   |   |    |
| 6. | i. Etching with piranha solution for 30 sec     | i. Heliobond                | Rely X Unicem  | Airborne particle abrasion in combination with piranha solution etching improves the adhesive properties of PEEK. | 97 |
|    | ii. Abraded with 50 $\mu$ m alumina particles   | ii. Clearfil Ceramic Primer |  |   |    |
|    | iii. Abraded with 110 $\mu$ m alumina particles |                             |  |   |    |
|    | iv. Rocatec system with 50 $\mu$ m alumina      |                             |  |   |    |
|    | v. Rocatec system with 110 $\mu$ m alumina      |                             |  |   |    |
| 7. | i. 50 $\mu$ m airborne particle abrasion        | i. Visio-link               | Self adhesive Rely X Unicem Cement   | Satisfactory bond strength after pre-treatment and conditioning.  | 98 |
|    | ii. 98% sulfuric acid                           | ii. Signum PEEK bond        |  |   |    |
|    | iii. Piranha solution                           | iii. Ambarino P60           |  |   |    |
| 8. | i. Sandblasting with 45 $\mu$ m alumina         |                             | Application of etchant and bonding agent followed by cementation with Rely X Unicem Cement | Better bond strength after pre-treatment and conditioning.  | 99 |
|    | ii. Rocatec system                              |                             |  |   |    |
|    | iii. 98% sulfuric acid for 5 sec                |                             |  |   |    |
|    | iv. 98% sulfuric acid for 30sec                 |                             |  |   |    |
|    | v. 98% sulfuric acid for 60 sec                 |                             |  |   |    |



**Table 4:** Fracture load of different materials

| Materials                                   | Fracture load |
|---|---------------|
| CAD-CAM milled 3-unit PEEK FPD              | 2354 N        |
| 3-unit pressed pellet PEEK                  | 2011N         |
| 3-unit pressed granular PEEK                | 1738N         |
| 3-unit Lithium disilicate glass-ceramic FPD | 950N          |
| 3-unit In-ceram Alumina FPD                 | 851N          |
| 3-unit In-ceram Zirconia                    | 841N          |
| 3-unit Zirconia FPD                         | 981-1331N     |
| PMMA based 3-unit FPD                       | 467N          |
| Composite resin based 3-unit FPD            | 268N          |

## 10. PEEK as Craniofacial Prosthesis Material

Trauma to the craniofacial region can have devastating defects leading to functional, esthetic or psychological consequences. Reconstruction of these defects is necessary to provide protection to the underlying anatomic structures, restoring function, form, symmetry and thereby esthetics. Presently, the most commonly used materials are autologous bone grafts and alloplastic materials. Autologous bone grafts have the advantage of good bone integration. However, as they are rigid, they are difficult to contour and create precision in certain areas. Alloplastic materials (methylmethacrylate, titanium mesh, hydroxyapatite, and polyethylene) are available in unlimited quantities and have no donor site morbidity. The main issue with alloplastic material is biocompatibility, making them less tolerant to infection. Alloplastic implants also require time in terms of intraoperative preparation, contouring, and fitting into the defect as they are not preformed to the defect.<sup>107,108</sup>

There are many reported cases in which PEEK material was successfully used as craniofacial reconstruction like in fronto-orbital reconstruction,<sup>109</sup> orbito-fronto-temporal reconstructions,<sup>107,108</sup> mid-facial reconstructions,<sup>110</sup> as a maxillary obturator<sup>111</sup> and as a mandibular reconstruction plate.<sup>112,113</sup> Available as a computer-designed, prefabricated prosthetic, PEEK Optima-LT Patient-Specific Implants (PSI) (Synthes Maxillofacial, West Chester, PA) was suggested as one of the most promising alloplastics calvarial replacements to date.

## 11. Maintenance of PEEK Prosthesis

Individual prophylaxis can be conducted with sonic toothbrushes as chances of abrasion with manual toothbrushes are more. For professional prophylaxis, air-abrasion devices using gentle powders like Air Flow Plus (AFP) are effective. Laboratory protocols should include gentle cleaning methods like Sympro or ultrasonic bath.<sup>114</sup>

## 12. Manufacturers of PEEK

Victrex; Synthes CMF; Kern GmbH Technische Kunststoffteile, Großmaiseid, Germany; JUVORA Ltd, Wyre, Lancashire, UK; Invibio Ltd., Thornton Cleveleys, UK; Evonik Corporation, Essen, Germany; Bredent GmbH & Co. KG; Solvay Speciality Polymers are some of the common manufacturing companies of PEEK.

## 13. Conclusion

Metallic materials like Titanium, Co-Cr, and its alloys continue to be the materials of choice for medical and dental fields because of their various biological and mechanical properties. Despite their advantages, these materials implicate some issues such as osteolysis followed by implant failure, scattered radiation, occasional hypersensitivity, allergy and possibly surface degradation related to peri-implantitis. A non-metallic material such as high-performance polymer polyetheretherketone (PEEK) has shown favorable mechanical and physical properties with similar elastic modulus to bone and dentin. PEEK can be used for a number of applications in dentistry including dental implants. Surface treatment of PEEK implant can increase its bioactivity. PEEK is also a good option for producing CAD-CAM fixed and removable prosthesis because of its better mechanical properties than acrylic or composite resin. So with this review, the conclusion can be drawn that the application of PEEK in Prosthodontics is providing a bright era in Prosthodontics.

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None.

## 15. Conflict of Interest

The authors declare that there is no conflict of interest.

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**Kavya Patali S**, Prosthodontist

### **Author biography**

**Pratul Kumar Agrawal**, Prosthodontist

**T Ashish**, Prosthodontist

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