PEEK in Fixed Dental Prostheses

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Contributor: Biyao Wang , Minghao Huang , Dang Pengrui , Jiahui Xie , Xinwen Zhang , Xu Yan

The success of a fixed dental restoration depends on three key factors: biomechanical behavior (wear resistance and fracture resistance), marginal fit, and aesthetics, generating extremely strict demands for the restoration material. Zirconia has become a popular alternative to metal in fixed dental prostheses, known for its excellent aesthetics. More importantly, zirconia exhibits better wear resistance than metal and alloys. PEEK is proposed as a promising alternative material to zirconia because of its superior mechanical properties. PEEK is also significantly less abrasive than zirconia.

polyetheretherketone properties adhesion bonding fixed dental prosthesis

1. Crowns

Regular mastication and progressive erosion result in unavoidable wear of the crown, and the crown material must possess considerable wear resistance [1]. Numerous authors have examined the wear resistance of PEEK crowns. Abhay et al. [2] and others [3][4] have reported that zirconia crowns exhibit greater displacement resistance than PEEK crowns, but are also more abrasive, and although PEEK showed greater susceptibility to displacement compared to zirconia, it also shows a more balanced distribution of stress through deformation because of its much lower elastic modulus (3 to 4 GPa vs. 210 GPa) [2]. Regarding wear, an in vitro study comparing polymethylmethacrylate (PMMA), PEEK, and silicate ceramic (SiO_2) crowns demonstrated the pivotal role of crown geometry in crown preservation [5]. The PEEK crown exhibited increasing material loss along with the elevation of the cusp inclination, while showing minimum material loss in comparison to PMMA and SiO_2 after thermal loading [5].

Regarding fracture resistance, PEEK exhibits superior flexural strength (140 to 170 MPa) compared to conventional materials, protecting restorations from bulk fractures [6][7]. Shetty et al. found that crowns with PEEK coping exhibited much greater strength than crowns with zirconia coping [8], and thermocycling had minimal effect on fracture resistance. Finite element analysis (FEA) has indicated that PEEK crowns and porcelain fused to metal crowns have similar stress distribution in dentin [9]. Tekin et al. reached a different conclusion, however, as a veneered PEEK crown reduced the stress concentration in dentin, post, and composite core in comparison to the porcelain fused to metal crown, while increasing the stress concentration in the cement layer of the post and crown [10]. Recent FEA modelling for implants with insufficient alveolar bone support has examined connected crowns, which can alleviate the stress concentrations at the margin of the crown and tooth [11]. Notably, PEEK is recommended as a long-term provisional crown material in cases where other auxiliary treatments are planned. When compared with polylactic acid and PMMA in vitro, PEEK exhibits the lowest marginal and internal gap values and the greatest fracture resistance [12]. Besides, Sulaya et al. conducted a one-year in vivo longitudinal pilot study that assessed the prosthetic performance of PEEK crowns and found that 90% were satisfactory under the modified Ryge Criteria, with a low incidence of fracture [13].

Precise margins are crucial to successful crown restorations, with failure resulting in adhesive dissolution, dentin hypersensitivity, secondary caries, and periodontitis. Crowns with PEEK coping had better margin fit and internal adaptation than crowns with zirconia coping, and both were clinically acceptable [14]. Variations in manufacturing techniques exert a significant effect on margin precision. Pressed PEEK exhibited a larger marginal gap than computer-aided design (CAD)- and computer-aided manufacturing (CAM)-milled PEEK, both of which stayed within the clinical acceptance limit [15]. As yet, only a few studies have been dedicated to examining the differences among various fabrication technologies, and further research is required.

2. Fixed Partial Dentures

Stress distribution, fracture resistance, and fracture pattern are primary considerations for fixed partial dentures (FPDs) [16]. The Young's modulus (3 to 4 GPa) of PEEK is lower than that of CoCr alloys (220 GPa) and zirconia (220 GPa) [17][18]. Given this advantage, when the occlusal force load is at the pontic, PEEK provides stress absorption for the abutment teeth, protecting them from fracture [19]. Campaner et al. used FEA to compare the mechanical performance of three-unit FPDs of acrylic resin, resin composite, and PEEK [20], and found that in the PEEK prosthesis, the connectors provided greater stress distribution than the other parts of the prosthesis. As to the cement layers, PEEK displayed the lowest strength of the cervical margin, indicating that PEEK could alleviate the stress concentration in FPDs. However, the highest strengthening of the occlusal region was also observed in PEEK.

Rodríguez et al. examined the potential of PEEK as an alternative FPD material [21] along with various fracture patterns and reported that CoCr registered the highest fracture values after thermocycling, followed by PEEK (3132 N) and zirconia; all were within the clinically acceptable range [22]. Moreover, in another study, Stawarczyck et al. [23] reported a lower fracture value (1383 N) of an uncemented three-unit milled PEEK FPD and noted that deformation appeared to start at 1200 N. Stawarczyck's group also studied the effect of the fabrication technique on fracture resistance in PEEK FPDs [24] and found that granulate pressed PEEK had a lower fracture value (1738 N) than milled PEEK (2354 N). In terms of the fracture pattern, pressed PEEK pellets and milled PEEK had fracture at the pontic without deformation, while deformation without fracture was observed in pressed PEEK granules [24]. Regarding the underlying mechanism, Niem et al. found that PEEK in a three-unit FPD had a superior capacity to absorb fracture energy via elastic deformation preceding rupture based on its favorable flexural modulus and on respective stress-strain curves marked by increased strain values [19]. The size of the connector is also thought to have a critical role in the fracture resistance of PEEK FPDs. Among the few studies that have concentrated on this, some [21][24] support a connector size of 16 mm^2 while others [23] have advocated smaller dimensions (7.36 mm^2, 11.3 mm^2). Other factors in FPD fracture include the presence or absence of veneer, aging, abutment models, and so on. Even with the varying degrees of difference in the design of the above-mentioned studies, PEEK can still be regarded as a viable alternative material for FPDs.

In terms of its clinical utility for FPDs, Rauch et al. have noted that PEEK requires less fabrication time and is lighter than zirconia, and although zirconia has exhibited a better aesthetic result than veneered PEEK, both are aesthetically acceptable [6]. PEEK FPDs provide satisfactory clinical outcomes when assessed by modified Ryge Criteria and the California dental assessment system [25]. Only 5% of PEEK FPDs failed because of de-bonding, while remaining restorations were maintained without fracture, and 10% showed marginal discoloration, but marginal adaption exhibited no significant change over one year.

Cekic–Nagas et al. compared the load bearing capacity of inlay-retained FPDs fabricated from PEEK vs. other resin-based materials [26] and found that PEEK had the highest load-bearing capacity and could be considered as an alternative to fiber reinforced composite materials. They and others [25] have found that the majority of fractures of inlay-retained PEEK FPDs occur at the connector. Tasopoulos et al. have recently published a case report describing a successful restoration of an inlay-retained PEEK FPDs [27]. Additional clinical trials are necessary to evaluate the long-term restorative quality.

3. Post-and-Core

Post-and-core material requires high fracture and fatigue resistance, accurate matching with the morphology of the root canal, and more importantly, a Young’s modulus similar to dentin (18.6 GPa) [28]. The elastic modulus of the post material plays a key role in the stress distribution within dentin, subsequently affecting the fracture performance of the restoration and the teeth [9]. Post materials with a Young’ s modulus closer to that of dentin usually generate favorable stress distribution, with high stress at the post and low stress at the weakened root and post–dentin interface [28]. Cast metal alloy posts and zirconia posts—which have much higher elastic moduli than dentin—generate concentrated stress at the root, which may result in the fracture of the root, while the posts remain intact [29][30]. Fiber-reinforced composite (FRC) posts exhibit more balanced stress distribution, and while the risk of root fracture is lower, the posts are more easily fractured [31]. Nevertheless, because of their excellent mechanical behavior, FRC posts have become the most commonly used material for post-and-core restoration, although there are still some disadvantages. The prefabricated FRC post cannot match the morphology of the natural root canal and requires a specially calibrated drill for canal preparation that may increase the depletion of dentin and the thickness of cement, subsequently raising the risk of root fracture and post debonding [32]. Recent results have shown that PEEK shows better aesthetic behavior than metal alloys and is comparable to FRC when used as post-and-core material; its low elastic modulus (3 to 4 GPa) is comparable to that of dentin (18.6 GPa), as are the elastic moduli of GFR-PEEK (12 GPa) and CFR-PEEK (18 GPa) [9].

FEA consistently confirms the potential of PEEK as an alternative material to FRC or glass fiber in post-and-core restoration. In terms of prefabricated posts, PEEK and glass fiber posts show similar intensity and stress distribution when trialed with an occlusal load [28], and PEEK posts display more favorable stress distribution and failure patterns compared to glass fiber and titanium posts in various structures of the restoration and teeth whether under mechanical or thermal stress [33]. Similarly, in comparison to the glass fiber post, the prefabricated PEEK post reduced the stress concentration within the post, post cement, and composite core, while exhibiting no significant effect within dentin [10]. Carbon fibers and glass fibers can be blended with PEEK to not only increase the stiffness of PEEK, but also to provide a more similar elastic modulus to dentin [34], and CFR-PEEK posts showed the lowest von Mises stress in dentin in comparison to FRC, GFR-PEEK, and polyetherketoneketone posts [9]. Moreover, the maximum stress occurred in the CFR-PEEK posts, and the finding that the stress was lower at the dentin–post interface suggests a protective effect conveyed by the similar elastic modulus [9].

Regarding the influence of the PEEK manufacturing technique, FEA is useful for predicting the mechanical behavior of PEEK in post-and-core restorations and for evaluating the accuracy of PEEK fabricated by different methods. The work of Lalama et al. has predicted higher accuracy of heat-pressed PEEK posts in comparison to CAD/CAM PEEK posts [35].

The superior properties of PEEK as post-and-core material are also evidenced in vitro and in vivo. PEEK posts showed the highest fracture resistance in comparison to polymer infiltrated ceramic (PIC) posts and FRC posts, but teeth had a less favorable fracture result with PEEK than with FRC [32]. PEEK posts exhibited a significantly lower fracture load than nickel-chromium (NiCr) alloy posts while presenting similar fracture resistance to nano-ceramic composites posts and fiberglass posts [36]. Özarslan et al. reported maximum fracture resistance in glass fiber posts, followed by zirconia posts and PEEK posts, and the fracture load of PEEK posts displayed no significant difference when restored with different size root canals [37]. Most failures of PEEK posts resulted from the decementation of post and core and were repairable [36][37]. Sugano et al. tested PEEK in flared root canals in a bovine tooth model but found that PEEK posts showed poor mechanical performance in comparison to glass fiber posts in the restoration of flared root canals [38]. PEEK is growing in popularity among clinicians as a post-and-core material because of its superior aesthetic and mechanical properties. Zoidis et al. have reported on a PEEK post-and-core restoration of a maxillary lateral incisor that was performed at a comparatively lower cost and had a satisfactory outcome [39]. Altogether, accumulating evidence has demonstrated the potential of PEEK to serve as a post-and-core material, but whether PEEK can increase the long-term survival of the teeth and restoration requires additional study.

4. Other Fixed Dental Prostheses

In addition to common fixed restorations, PEEK has also been tested in vitro for possible use in endocrowns and inlays. Because of decementation, PEEK endocrowns had the lowest retention force in comparison to infiltrated ceramic, partially stabilized tetragonal zirconia, and lithium disilicate ceramic endocrowns [40]. Although PEEK failed to provide sufficient retention, it showed a positive failure pattern, in which the tooth was protected from fracture [40]. When tested as inlay material, CAD/CAM and milled PEEK have also exhibited satisfactory fracture resistance in comparison to direct resin filling [41].

In conclusion, because of the deformability related to its lower elastic modulus, PEEK can provide favorable stress absorption for abutment teeth, adjacent tissues, and the cementation layer in fixed dental prostheses when compared with metal alloys and zirconia [42]. PEEK not only protects the abutment teeth and the cortical bone, but it also decreases the incidence of de-bonding, which contributes considerably to its good success [21]. The mechanical strength of PEEK does not match that of the conventional materials, which can lead to fracture of the

PEEK itself [43]. To address this, glass fibers, carbon fibers, and other particles can be used to reinforce PEEK and to obtain a more perfect balance between elasticity and strength [44]. Unfortunately, GFR- and CFR-PEEK exhibit a worse aesthetic property for fixed dental prosthesis, and it is difficult to reach a satisfactory aesthetic outcome even with composite resin veneers [44]. Additionally, whether the accumulating deformation would result in a restoration misfit requires further in vitro and in vivo trials.

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