# PEEK Material in Terms of Biomechanics and its use in Single Implant Prosthesis: A Review

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## Abstract

The aim of the study was to perform a review on biomechanics behavior of polyetheretherketone (PEEK) on prosthetic component of single unit dental implant including abutment, screw and crown.

Electronic search was performed on PUBMED using combination of the following search terms: PEEK, Polyetheretherketone, BioHPP, FEA, FEM, Finite element, Stress, Mechanical properties, Dental implant, Abutment, Implant abutment. The search period spanned from 2012 to 2022, 158 results were found, 25 studies were selected.

The findings reported fracture strength, failure mode and finite element analysis (FEA) in single-unit implant prosthesis; abutment, crown and screw. Fracture analysis of abutment and crown shown that the failure mode and means of the fracture strength varied between materials however they could be considered to have fracture strengths suitable for clinical application. In FEA show that the use of PEEK crown reduces the stress on itself and could reduce stress transfer to the implant surrounding bone. Contrary, PEEK screw shown significant inferior results compare to Titanium screw.

Indication for the use of PEEK as implant abutment and crown is suitable for clinical application. However, PEEK screw is still questionable and should be considered carefully. Further, clinical trials comparing are needed to strengthen the evidence.

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## Introduction

Nowadays, the implant-rehabilitation protocols have been redefined in order to satisfy patient's increasing expectations in terms of comfort, aesthetic and shorter treatment period. Consequences, immediate implant placement after tooth extraction with immediate loading has become more common.[1] This make interim implant prosthesis play a role in terms of maintaining and contouring soft tissue profile. Even though the commercial titanium is conventionally recognized as material of choice for fabrication convention temporary abutment. However, the metallic color of titanium still be a major problem for the esthetic requirement.

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All-ceramic materials have been suggested to overcame the esthetic complication as they have proper physical properties, lower bacterial adhesion[2] and absence of gingival discoloration.[3] Nonetheless, All-ceramic materials, for example, zirconia abutment was reported to have higher abutment and crown fracture[3] and caused more extensive wear on the implant interface compared with titanium abutment.[4,5] Moreover, its extreme rigidity requires high precision laboratory procedures[4] and almost impossible to adjusted chairside. Those limitation make zirconia an improper material for provisionalization.

Recently, there has been an increasing interest in polyetheretherketone (PEEK) material as an alternative to titanium due to its highly biocompatibility, preferable color, economical price, and chairside adjustment ability. PEEK is a polycyclic aromatic semi-crystalline thermoplastic polymer which has been used in orthopaedic surgery since 1990s as its mechanical and physical properties resembling to those of bone.[6,7] Unfilled PEEK was first introduced in 3 forms versions: PEEK-LT1, PEEK-LT2 and PEEK-LT3. Onward, the filled versions were introduced into the market such as BioHPP (Bredent, UK), and PEEK-OPTIMATM (Invibio Biomaterial Solutions Co., UK)[6] in order to improve its mechanical properties.[7] To date, PEEK material is initially used in dental implantology for example temporary abutment, healing abutment and digital guided sleeve. PEEK components can now facilely fabricate by injection molding, extrusion and compression molding8, digitally designed and 3D printed, PEEK “blanks” (Juvora)[6] and also with computer-assisted design / computer - assisted manufacturing (CAD/CAM) milling.[7]

In addition, due to its low elastic modulus, PEEK crowns were expected to serve the damping effect that could prevent overloading force on the peri-implant bone by creating shock-absorbing effect within the implant-prosthesis complex. Moreover, its low hardness was also expected to reduce wear rate on opposing teeth.[9,10] Not only the crown on implant that PEEK was expect to help reduce complications but also the implant abutment screws. Abutment screws that made from PEEK was expected to limit the stress shielding between implant figure and surrounding bone. Besides, due to its low friction coefficient that make it have higher torque efficiency and was expected to be more uncomplicated to remove in case of screw fracture .[11]

The aim of this review was to perform a review on biomechanics behavior of PEEK material on prosthetic component of single unit dental implant including abutment, screw and crown.

## Materials and methods

All the data was collecting through PubMed. using combination of the following search terms: PEEK, Polyetheretherketone, BioHPP, FEA, FEM, Finite element, Stress, Mechanical properties, Dental implant, Abutment, Implant abutment. The search period spanned from 2012 to 2022, 158 results were found and only 25 studies were selected.

The first search term is "(polyetheretherketone or PEEK or BioHPP) and “implant abutment””, 27 results were found and 10 studies were selected.

The second search term is "(polyetheretherketone or PEEK or BioHPP) and “abutment” , 70 results were found and 24 studies were selected.

The third search term is"(polyetheretherketone or PEEK or BioHPP) and (dental implant) and (Mechanical properties)”, 20 results were found and only 1 study were selected.

The fourth search term is"(“PEEK” or “polyetheretherketone”) and (“FEA” or “Finite element” or “stress”) and (“dental implant” or “abutment”)”, 41 results were found and 21 studies were selected.

All the selected studies were selected under the criteria that the data was relevant to the thesis. The reviews, Meta-analysis and systematic reviews were excluded, only in vitro and in vivo studies that provided full paper were included, then duplicates studies were removed. The total number of the studies used in the thesis is 25 studies.

*1. Mechanical properties for PEEK material*

Aimed of the materials that used in single implant prosthetic is not only to restore the esthetic but also to restore the function of enamel and dentin during mastication that generate compression forces on the prosthesis units. As the mechanical role of enamel is grinding food, its hardness and abrasion resistance were such critical mechanical properties to consider. Whereas the mechanical role of dentin is to absorb the bite force. Therefore, the mechanical properties that need to be prioritized are maximum stress-strain, Young’s modulus, and fracture resistance.[12]

PEEK (Polyetheretherketone) is a high-performance engineering, tooth color thermoplastic with outstanding resistance to high temperature and long-term chemical exposure. In this study, the using of PEEK in implantology was focus only in terms of using PEEK as a single implant prosthesis, including of crown, abutment and screw. One of the most important properties of PEEK that believed to be a promising choice for prosthetic implant biomaterial is Young’s modulus. Young’s modulous of PEEK is 3-4 GPa and can be modified easily by adding carbon fibers to increase the values up to 18 GPa comparable to cortical bone; 14 GPa, to ensure more uniform stress distribution in peri-implant bone[6,12,13], which consequently reduce bone resorption. High tensile strength, compressive and fracture resistance also important properties for implant crown, abutment and screw in order to prevent fracture and improve functional stability. Tensile strength of PEEK is 80 MPa and can be up to 120 MPa when modified (BioHPP) which is comparable to dentin; 104 MPa and enamel; 46.5 MPa, while titanium is 954-976 MPa and zirconia is 1,000 MPa [14, 15, 16, 17, 18, 19]. However, the fracture resistance value is not indicated here as its very wide range values due to the differences of sample preparation, tooth position and stimulations.

*PEEK as implant abutment*

PEEK has been used for the manufacturing of single implant abutments by many implant companies and can be categorized roughly into two group; PEEK abutment and PEEK substructure on Titanium base. One-piece PEEK abutment is the abutment that the entire piece made from PEEK material including the connection part, for example, PEEK temporary abutment (Biohorizon® Implant Systems Ins., Birmingham, AL, USA), Temporary abutment in PEEK (B&B Dental S.r.l., Italy). Other types of PEEK abutment is PEEK substructure on Titanium base such as BioHPP SKY elegance abutment (Bredent, Germany), RN synOcta Temporary Meso Abutment (Institut Straumann AG, Basel, Switzerland). However, it was recommended to use for temporary purposed only.

*1.1 PEEK as implant abutment compare to other material in terms of fracture resistance.*

Regarding the fracture resistance of the different materials, there were studies reporting information about mean fracture load values between titanium, zirconia and reinforced-PEEK only in Tüsrksayar AA, et. al. that also compared with polyetherketoneketone (PEKK) abutments[4] and Al-Zordk et. al. that compared zirconia and ceramic-reinforced PEEK abutment with lithium disilicate abutment combine with Ti-base.[20] The six studies used Ti implant figure correspond with Ti-based that combine with different materials as substructure unit and crown. Most of them used maxillary anterior teeth as a tested tooth[3, 4, 21] except Al-Zordk et. al.[20] that used maxillary premolar and Elsayed et. al.[22] that used mandibular first molar.[22] The implant figures or implant analogue were embedded perpendicularly or 30 degree in different type of material such as epoxy case[20], metal plates[4], autopolymerizing resin[3] or in polyoxymethylene cast.[21] The specimens in five studies were subjected to artificial aging through dynamic loading and thermal loading except Santing HJ et. al.[23] After the stimulation, the fracture was done using universal test machine with compressive load until failure occurs. The value of the fracture strength for each specimen were recorded.

The results shown that fracture strength values were varies depend on type of material, Bonding regimen, abutment preparation, abutment design, tooth morphology, implant diameter and angulation of loading force. For example, fracture resistance of PEEK abutment shown lowest value in Santing HJ et. [PR8]al. in group I (95+21 N) that used Straumann synOcta Temporary Meso Abutment with direct composite veneer (Solidex, Shofu). However, in order to make in fit with the mold used to fabricate composite resin central incisor crown, the researcher claimed that they had to aggressively reduced the size of the PEEK substructure and that might affect the fracture resistance of the material.[23] Contrary, PEEK abutment together with nano-hybrid composite mandibular first molar crown shown much higher fracture resistance value (1,733+ 169 N) in Elsayed A et. al.[22] Nevertheless, the six studies[3,4,20,21,23,24] reported results in quite similar trend. As titanium shown significantly higher fracture resistance value compared to other materials, followed by zirconia and reinforced-PEEK. While PEKK and lithium disilicate abutment shown significantly lowest valued compared to zirconia.

Eventually, reinforced PEEK abutments may consider as an alternative to zirconia substructure with Ti-base for single-implant restorations in anterior region.[3, 4, 23] As the mean anterior masticatory loading forces reported to be around 206 N.[23] So, the mean fracture strength contributed in the five studies[3, 4, 21, 23, 24] for this region were generally exceeded the mean maximum masticatory force. While it is recommended to cautiously use in posterior region[20,22] as maximum masticatory force reported in premolar region were around 200-445 N and 900 N in molar region.[20]

*1.2 PEEK as implant abutment compare to other material in terms of failure modes.*

All the studies that evaluate the fracture resistance also repot the types of failure. After the specimens were examined under compressive load with universal testing machine and recorded the fracture resistance value of each specimen, the types of fractures were examined under microscope, recorded with digital photos and then categorized in groups. Each studied classify the failure mode in its own classification. Seven studies[3, 4, 20, 21, 22, 23, 24] reported failure mode of PEEK abutments supporting different crown materials. However, under high compressive load, titanium abutments tend to has higher incidence in screw fracture and implant figure or analogue deformation.[3, 22, 23]

Crown and abutment fracture were found in zirconia abutment on Ti-base. While, more incidence of crown fracture and separation of the abutment-crown complex from Ti-base without damage to the substrates were found in reinforce-PEEK abutment.[3, 4, 24] Türksayar AA et. al. described the separation of abutment-crown complex as the weak bond of PEEK to titanium substructure. As PEEK has inert surface, so it needs additional adhesive systems to enhance the resin bonding strength of its surface.[4] However, the PEEK abutment combination with Ti-base was manufactured by conventional injection molding technique to make PEEK lock mechanically with the grooves on Ti-base, without any chemical bonding. Even this failure mode occurred in 40% of the cases reported in Barbosa-Júnior et. al., it is considered as a reversible failure and can be rebonded easily by luting agent.[24] However, the development of luting cement of using of one-piece PEEK abutment is also of interest. The debonding was also occurred in Santing et. al. that reported 5 out of 32 specimens of PEEK abutment-crown complex had adhesive failure between the composite resin and the abutment. Anyhow, in this experiment the composite resin was directly veneer on PEEK abutment without any surface preparation or using chemical bonding.[23] For the bonding protocol of PEEK, according to the implant manufacturer and previous studies, it has been reported that primer adhesive that has methyl methacrylate (MMA) such as Heliobond®, Luxatemp Glaze & Bond®, Visiolink® and Signum PEEK Bond®[25] can contribute positive effects on PEEK bonding strength.[4] Silthampitag P et. al. had experimented on the effect of surface pretreatments on resin composite bonding to PEEK, which compared four types of pre-treatment protocol on PEEK surface (no pretreatment, etched with 98% sulfuric acid, etched with piranha solution and sandblasting with 50 µm alumina) together with Heliobond® contributed highest shear bond strength compared to other methods.[25]

Moreover, it was suggested in Elsayed A et. al. that failure mode could depend on both crown and abutment material used as they both effect on the different modulus of elasticity. For example, both composite resin and lithium disilicate crown on titanium and zirconia abutments shown favorable fracture of crown rather than composite resin on reinforced-PEEK abutment that shown fracture on both abutment and crown.[22] Conversely, Barbosa et. al. suggest that the fracture pattern was more influenced by the crown material than by the abutment material. As the radial crack of the crown occurred mostly in lithium disilicate crown equally with both zirconia and PEEK abutment. Where the fracture of screw and implant platform was the most prevalent failure pattern that occurred in translucent zirconia crown both on zirconia and PEEK abutment.[24] In this point, further literature about the effect on different crown material used in each type of abutment is recommended to be performed.

Finally, form the literature reviews found that the failure mode for using PEEK abutment usually caused the crown fracture complication. However, most of the specimens fractured when the given loading force were exceeded the mean of maximum masticatory forces. The summary of the studies included in the review of using PEEK as abutment in terms of fracture resistance and failure modes is shown in Table 1.

*1.3 PEEK as implant abutment compare to other material in terms of finite element analysis.*

The three-dimensional (3D) finite element analysis (FEA) was done in order to evaluate the stress distribution in implant-bone interface and in each implant component. The initial hypothesis was that PEEK abutment could act as a shock absorber and help reduce stress accumulation at the implant connection and peri-implant bone. However, this hypothesis was partially rejected. It is found that, the use of different materials did not cause a significant different change with stress distribution on implant and peri-implant bone.[26, 27, 28, 29, 30, 31] However, there were differences in stress distribution patterns in the implant-prothesis-complex with different crown-abutment material combination[27, 29, 32, 33] and implant placement depth[34].

The abutment with lower elastic modulus could generate higher stress concentration in the implant component, restorative crown and peri-implant bone[26, 27, 35] which led to different modes of failure of the prosthesis complex. For example, Huang Z.L. et. al. stated that the use of PEEK abutment together with PEEK crown could generated higher stress concentration on Ti-bases compared to Zirconia abutment (PEEK; 196.30 MPa, Zr; 95.81 MPa) in standard length implant.

The stress concentration in abutment screws were also shown differences. In PEEK abutment, the stress was concentrated on the head and middle part of the screw, while in case of Zr abutment, the stress was concentrated mainly at the middle part of the screw.[27]

Although the maximum stress values were higher in PEEK abutment with Ti-base, the stress distribution patterns were less dangerous and has lower risks of technique complication.[27] Tekin et. al. observed that PEEK material reduces the stresses caused by the force applied only on itself, but increase the stresses on the restorative crown. This could explain by PEEK low elastic modulus, 60 times lower than Zirconia, that generate greater deformation in abutment, leading to greater stress on the restorative crown.[35] Not only the crown, but PEEK abutment also transmitted the stress to implant and screw in case of one-piece PEEK abutment, while transmitted the stress to Ti-base, implant and screw in case of PEEK abutment with Ti-base.[26, 27, 28, 35] Hence, Tekin et. al. and Huang Z.L. et. al. suggested to use PEEK abutment (with PEEK connection) together with PEEK crown as the stress dispersed more evenly.[27, 28] They also found that this combination of PEEK crown-abutment complex could significantly reduce stress on abutment, crown and screw.[35]

Despite the fact that PEEK abutments demonstrated higher von Mises stress values compared to titanium and zirconia abutment, they not exceeded 550 MPa, which is the yield strength of the titanium implant that led to failure.[26, 36, 37] However, further clinical studies are needed to determine their long-term performance. The summary of the studies included in the review of using PEEK as abutment in terms of finite element analysis is shown in Table 2.

*2. PEEK as crown on implant*

Hooke's law states that, the higher the modulus of elasticity, the lower deformation occurs in that material and the more likely the forces will be transferred through the crown directly to the implant. However, the lower the modulus of elasticity, the higher deformation occurs in crown itself, reducing the forces that will be transferred to the implant.[38, 39] Many studies showed similar results with the "Hooke's law". Cantó-Navés et. al. evaluated the stress transferred in the titanium abutment and cortical bone using different materials of crown. It turned out that using PEEK as a framework crown material can dissipated stress at the bone faster than when using metal.[40] Taha et. al. also compared force damping behavior of different implant-supported crown; zirconia, BioHPP, VITA Enamic and e.max CAD and found that PEEK and VITA Enamic required longer time to reach the maximum force than in E.max CAD and zirconia. So it can be conclude that, the more rigid the material the less will be its damping effect on the load transmission to the abutment.[38]

The fracture resistance and failure mode were tested in PEEK crown. It is found that PEEK has higher fracture resistance compared to lithium disilicate but significantly lower compared with zirconia.[9, 10, 41, 42] However, Donmez et. al. tested the crowns with three different designs including screw-cement crown, crown on zirconia-titanium base abutment and cementable crown. They found that Ti abutment restored with cementable crown showed highest fracture resistance compare to other design.[42] As the presence of the screw channel may cause the weakening effect on the crowns.[41] Even though Elsayed A. et. al. stated that ceramic-reinforced PEEK crowns over titanium and zirconia abutments showed high fracture resistance comparable to the most commonly used ceramic material[9], but in clinically, PEEK might veneer with composite for esthetic purpose and that might be a critical factor for its success.[41]

Furthermore, the PEEK crowns were also tested under parafunctional loading. Mourya et. al. suggested that the straight abutment with PEEK crown could be given to bruxism patient to reduce stress concentration in implant surrounding bone, which consequently help preventing implant failure.[30] The summary of the studies included in the review of using PEEK as crown on single implant is shown in Table 3.

*3. PEEK as implant abutment screw*

PEEK abutment screw is recommended by the manufacturer (Juvora) that it could be tightened with a torque not over than 15 Ncm. In case of over torque or overloading of functional masticatory forces, according to its high Young's modulus (120 GPa), the PEEK screw can be plastically deformed. Furthermore, PEEK screw, metal-free, cannot be corroded which could reduce risk of screw fracture also reduce risk of material abrasion from inner threading of a conventional implant. Even though the screw fracture occurs, based on its low hardness, PEEK screw was found to be easier to remove compare to conventional titanium screw.[43, 44] For more than that, it also has similar median rotation angle of abutment after the rightward force was applied.[45]

Conversely, after the fracture resistance analysis comparing between PEEK and Ti was done. It is clear that PEEK screw has lower fracture strength (145-196 N) compare to Ti screw (263-512 N).[11,45] The maximum tensile strength also examined in Schwitalla AD et. al. and was found that 50% continuous carbon fibers reinforced-PEEK screw has maximum tensile strength at 191.69 + 36.33 MPa which significantly lower from Ti screws that amounted 1196.29 + 21.4 MPa.[43]

Even though using the PEEK screw is still questionable. Chen X et. al. stated another interesting application of PEEK on Ti screw. They found that coating PEEK on Ti screw could effectively improve the stability of implant-thread connection, reduce wear of internal implant internal thread, prevent screw loosening and easier to removed. This was explained as PEEK-coating screw could reduce friction coefficient which effect on increasing of clamping force. Moreover, Ti screw that coated with PEEK was proved to have no significant effect on the fracture load compared to conventional Ti.[44] The summary of the studies included in the review of using PEEK as abutment screw is shown in Table 4.

## Conclusions

PEEK is a biocompatible material with favorable mechanical properties that allow to use in dental implantology. The in vitro studies showed that the indication for the use of PEEK as implant abutment and crown is suitable for clinical application, even though it could not reduce the force transferred to peri-implant bone as it was expected. However, PEEK screw is still questionable and should be considered carefully. Further, clinical trials comparing in terms of esthetic performance, failure mode and biomechanical responses are needed to strengthen the evidence.[46, 47]

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## Declaration of Interest

The authors report no conflict of interest.

| | Author (year) | Experimental groups | Fracture strength values (means) | Failure mode |
|---|---|---|---|---|
| 1 | Al-Zordk W et. al. (2020) | Zirconia (Zr), lithium disilicate (LD), or ceramic-reinforced PEEK (PE) | Zr has highest fracture strength. There was significant difference between Zr and PE groups, no significant difference between L2 and PE groups. | Zr : Complete vertical fracture into 2 halves above shoulder of Ti base<br>LD: Complete vertical fracture above shoulder of Ti base<br>PE: Complete vertical fracture into 2 halves above shoulder of Ti base |
| 2 | Atsü SS et. al. (2019) | Ttitanium (Ti), zirconia (Zr), and ceramic-reinforced PEEK (BioHPP) | The fracture strengths were significantly higher in Ti compared to Zr and BioHPP. No significant difference was observed between groups Zr and BioHPP | Failures generally occurred due to fracture of the screw in group Ti, abutment and crown in group Zr, and crown in group BioHPP. |
| 3 | Barbosa-Junior et. al. (2020) | Customized hybrid abutment material (PEEK or YZ) and the monolithic crowns (TZ or LD) | In PEEK abutment, LD and TZ crowns showed no statistical difference; however, in the YZ abutment, the TZ crown presented a load at failure value that was statistically higher than that for LD. | Failure pattern analysis revealed a higher prevalence of crown fracture for LD groups, while screw/implant platform fractures were shown for TZ groups. |
| 4 | Elsayed A et. al. (2021) | Titanium (T), zirconia (Z) and ceramic-reinforced PEEK (P). Each group was subdivided, according to the restorative crown material, into two subgroups; nano- hybrid composite (C) and Lithium disilicate (L). | The fracture strength values varied from a minimum of 1639 ± 205 N for group PL to a maximum of 2949 ± 478 N for group ZL. | The abutment material influenced the fracture strength and failure mode of the restoration. A combination of nano-hybrid composite showed most favorable mode of failure within the test group |
| 5 | Rosentritt N et. al. (2015) | Ten systems of screw-retained implant and adhesive base combinations (n = 8/ group) were restored with zirconia or polyetherketone (PEEK) abutments and identical full- anatomical zirconia crowns. | Fracture data significantly varied between the individual systems (minimum: 371 N; maximum: 763 N). | Seven systems survived TCML without any failure.The other three systems showed loosening and fracturing of the screw or debonding between base and abutment. None of the systems showed any fracture of the crown or failed bonding between abutment and crown. |
| 6 | Santing HJ et. al. (2012) | Three types of provisional abutments, RN synOcta Temporary Meso Abutment (PEEK), RN synOcta Titanium Post (Ti), and Temporary Abutment Engaging NobRplRP (Ti) were used, and provisional screw-retained crowns using composite resin (Solidex) were fabricated for four different locations in the maxilla. | No significant difference was found between different abutment types. Only for the position of the maxillary central incisor, composite resin crowns on PEEK temporary abutments showed significantly lower ($p < 0.05$) fracture strength ($95 \pm 21$ N) than those on titanium temporary abutments ($1{,}009 \pm 94$ N). | The most frequently experienced failure types were cohesive fractures of the composite resin crowns, followed by screw loosening. |
| 7 | Türksayar AAD et. al. (2021) | Zirconia (Zr), reinforced PEEK (RPEEK) and PEKK titanium base abutments were divided in to 3 group | PEKK abutments was significantly lower than the Zr and RPEEK abutments. A significant discrepancy was not detected between RPEEK and Zr abutment. | Failures usually formed due to crown or abutment fracture, plastic deformation of the titanium base or screw fracture in the Zr group, crown fracture or separation of the abutment-crown complex from the titanium base in the reinforced PEEK group, and abutment fracture without crown deformation in the PEKK group. |

**Table 1.** The review of using PEEK as abutment in terms of fracture resistance and failure modes.

| | Author (year) | Experimental groups | Result |
|---|---|---|---|
| 1 | Bataineh K et. al. (2019) | Five distinct models using a combination of titanium, CRF-PEEK, lithium disilicate for implant/abutment materials are studied. | No significant difference in the distribution pattern of stress at implant-bone interface among the different material models studied. |
| 2 | Huang ZL et. al. (2021) | Two FEA models were designed, one each for short implant (6 mm) (Group S) and standard implant (10 mm) (Group C). In each group, two abutment materials were used, Polyetherether- ketone (PEEK) and Zirconia (Zr), with two types of crowns, PEEK and Polymer-infiltrated ceramic-network (PICN). | PEEK is more suitable for hybrid restorations of short dental implant |
| 3 | Kaleli N et. al. (2018) | Six different models were created according to combinations of restoration materials (translucent zirconia [TZI], lithium disilicate glass ceramic [IPS], polymer-infiltrated hybrid ceramic [VTE], and customized abutment materials (PEEK and zirconia). | Zr abutments exhibited higher stress than PEEK. The stress distributions in the implant and peripheral bone were similar. |
| 4 | Mourya A et. al. (2021) | The models were divided in two group; CFR-PEEK implant and group titanium implant.Each group was subdivided based on implants with three different abutments (straight, 15°, 25° angled abutments) and having two different prosthetic crowns: porcelain fused to metal (PFM) and polyetheretherketone (PEEK). | CFR-PEEK and titanium implants produced similar stress in bone under vertical and oblique loading. Straight abutment showed better results than 15 and 25° angled abutment in all groups. |
| 5 | Schwitalla A.D et. al. (2015) | Type 1 completely consisted of titanium, Type 2 of a powder-filled PEEK and Type 3 of Endolign s. | All types showed a minimum safety foctor of cortical bone and has similar stress distribution. PEEK implant showed higher stress within the adjacent cortical bone. |
| 6 | Tamrakar SK et. al. (2021) | The models were divided into 2 groups according to the type of implant: the CFR-PEEK group; and the Ti group. Each group was subdivided to imitate 5 different restorative crown materials (PEEK, zirconia, porcelain fused to metal (PFM), metal, and acrylic resin). Each implant model was loaded verti- cally (200 N) and obliquely (100 N). | CRF-PEEK implants with different restorative crowns generated smaller stress compare to Ti implants in oblique loading, whlie generate similar stress in vertical loading. This could help reduce lateral stress on implants as well as crestal bone loss. |
| 7 | Tekin S et. al. (2019) | PEEK and titanium abutments, metal-ceramic, and monolithic PEEK upper central dental restorations were made on four titanium implants with diameters of 3.8 mm and 10.5 mm and four groups were obtained. | PEEK crown reduces the stresses on itself and the use of PEEK abutment increases the stresses on the crown. The stress on the implant system can be changed through the usage of different prosthetic material. |
| 8 | Tretto PHW et. al. (2020) | implant materials—titanium, porous titanium, titanium-zirconia, zirconia, reinforced fiberglass composite (RFC), and polyetheretherketone (PEEK); and abutment materials—titanium, zirconia, RFC, and PEEK; implant macrogeometry— tapered of trapezoidal threads (TTT) and cylindrical of triangular threads (CTT) (ø4.3 mmx11 mm). | Less rigid abutments (Reinforced fiberglass composite and PEEK) associated with titanium implants led to higher stress in the implant and in peri-implant bone tissue. |

**Table 2.** The review of using PEEK as abutment in terms of finite element analysis.

| | Author (year) | Experimenta groups | Evaluation | Result |
|---|---|---|---|---|
| 1 | Elsayed A et al (2019) | 48 identical custom-made CAD/CAM abutments milled out of titanium or zirconia were divided into six test groups of eight specimens each. The groups were assigned as follows: titanium abutments restored with zirconia crowns (TiZ), with lithium disilicate crowns | fracture strength (N) and fracture patterns | TiZ = 4,926 N; TiL = 3,706 N; TiP = 3,878 N; ZrZ = 5,529 N; ZrL = 2,826 N; and ZrP = 3,967 N. |
| 2 | Huang ZL et. al. (2021) | 2 FEA models were designed, one each for short implant (6 mm) (Group S) and standard implant (10 mm) (Group C). In each group, two abutment materials were used, Polyetherether- ketone (PEEK) and Zirconia (Zr), with two types of crowns, PEEK and Polymer-infiltrated ceramic-network (PICN). | FEA | Using the PEEK crown, the stress was better dispersed with PEEK abutment compared to Zr abutment. |
| 3 | Tekin S et. al. (2019) | PEEK and titanium abutments, metal-ceramic, and monolithic PEEK upper central dental restorations were made on four titanium implants with diameters of 3.8 mm and 10.5 mm and four groups were obtained. | FEA | PEEK crown reduces the stresses on itself and the use of PEEK abutment increases the stresses on the crown. The stress on the implant system can be changed through the usage of different prosthetic material. |
| 4 | Preis V et al 2019 | 168 crowns were fabricated from different CAD/CAM-materials (n = 8/material): ZLS (zirconia-reinforced lithium silicate ceramic; Suprinity, Vita-Zahnfabrik), COB (compos- ite; Brilliant Crios, Coltene), COL (composite; Lava Ultimate, 3M Espe), PMV/PPV (polyether ether ketone (PEEK) + milled composite veneer/composite paste veneer; BioHPP + HIPC veneer/Crealign veneer, Bredent), COH (composite; Block HC, Shofu), and ZIR (zirconia; IPS e.max ZirCAD, Ivoclar-Vivadent) as reference. Three groups were designed simulating the following clinical procedures: (a) chairside procedure ([CHAIR] implant crown bonded to abutment), (b) labside procedure ([LAB] abutment and implant crown bonded in laboratory, screwed chairside), and (c) reference ([TOOTH] crowns bonded on human teeth). | Fracture force (N) and failure mode | The other groups survived fatigue testing without failures. Fracture forces varied between 921.3N (PPV) and 4817.8N (ZIR) [CHAIR], 978.0N (COH) and 5081.4N (ZIR) [LAB], 746.7N (PPV) and 3313.5N (ZIR) [TOOTH]. Significantly different fracture values were found between materi- als in all three groups. Only ZLS crowns provided no significant differences between the individual groups. |
| 5 | Yazigi C et al (2020) | Forty custom-made CAD/CAM one-piece screw-retained restorations were milled out of 5 different monolithic materials (n=8); Z: zirconia, L: lithium disilicate, P: ceramic-reinforced polyetheretherketone (PEEK), C: nano-hybrid composite resin and E: polymer-infiltrated ceramic-network. | Fracture strength (N) and Interquartile range (N) | The median values of fracture strength varied from a minimum of 670 N for group E to a maximum of 2,645 N for group Z. |
| 6 | Donmez 2021 | 144 identical crowns were fabricated from zirconia-reinforced lithium silicate (ZLS), leucite-based (LGC), and lithium disilicate (LDS) glass-ceramics, reinforced composite (RC), translucent zir- conia (ZR), and ceramic-reinforced polyetheretherketone (P). These crowns were divided into 3 subgroups according to restoration design: cementable crowns on a prefabricated titanium abutment, cement-retained crown on a zirconia-titanium base abutment, and screw-cement crown (n = 8). | Fracture force and failure mode | ZR presented the highest fracture resistance .LGC showed the lowest fracture resistance. Fragmented crown fracture was predominant in most of the restorations. |
| 7 | Taha 2021 | Titanium inserts (N=84) were screwed to implant analogs, scanned to design zirconia abutments, and divided into 4 groups to receive CAD-CAM fabricated crowns in 4 materials: zirconia, polyetheretherketone (PEEK), polymer-infiltrated ceramics (VITA Enamic), and lithium disilicate (e.max). The crowns were subdivided as per the luting agent: none, interim cement, and adhesive resin cement. | Loaded force and slope change | Cementation of rigid materials significantly increased slope loss, indicating enhancement in their force-damping behavior, whereas less-rigid materials benefit less from cementation. |
| 8 | Cantó-Navés 2021 | six implant-supported prostheses made from different materials were simulated: metal (MET), metal-ceramic (MCER), metal-composite (MCOM), carbon fiber-composite (FCOM), PEEK-composite (PKCOM), and carbon fiber-ceramic (FCCER). | The stress transferred under dynamic loading | The use of PEEK or carbon fibers as framework materials made stress dissipate faster than when using metal at the bone. |
| 9 | Mourya A et. al. (2021) | The models were divided in two group; CFR-PEEK implant (n=6) and group titanium implant (n=6).Each group was subdivided based on implants with three different abutments (straight, 15̊, 25̊ angled abutments) and having two different prosthetic crowns: porcelain fused to metal (PFM) and polyetheretherketone (PEEK). | FEA | PEEK crownproduced lesser stress than PFM crown under vertical and oblique loading |

**Table 3.** The review of using PEEK as crown on single implant.

| | Author (year) | Implant | Screw | Result |
|---|---|---|---|---|
| 1 | Chen X et. al. (2020) | Ti | Ti (control)<br>PEEK-1 (screw coated with 30um PEEK)<br>PEEK-2 (screw coated with 60um PEEK)<br>PTFE-1 (screw coated with 30um PTFE)<br>PTFE-2 (screw coated with 60um PTFE) | PEEK coatings could effectively improve the stability of implant threaded connection, and reduce wear of implant internal thread. PEEK coating may be a suitable way to prevent screw loosening |
| 2 | Neumann EA et. al. (2020) | Ti (Titanium Fix 3.75x15mm) | Ti<br>PEEK<br>30% CR-PEEK | PEEK screws have lower fracture resistance , in comparison with titanium abutment screws |
| 3 | Schwitalla AD et. al. (2016) | Ti (Camlog) | Ti<br>TiO2-20 (Milling)<br>cCF-50 (Milling)<br>sCF-15 (Injection Molding)<br>sCF-40 (Injection Molding) | PEEK reinforced by >50% continuous carbon fibers would be the material of choice |
| 4 | Stimmelmayr M et. al. (2020) | Zr (Swiss dental solution) | gold (n=12)<br>Ti (n=12)<br>PEEK (n=12) | PEEK screws have lowest fracture resistance, while gold screws have lowest rotation angle. |

**Table 4.** The review of using PEEK as abutment screw.

## References

1. Singh M, Kumar L, Anwar M, Chand P. Immediate dental implant placement with immediate loading following extraction of natural teeth. National journal of maxillofacial surgery 2015;6(2):252-255.
2. Gomes AL, Montero Martín J. . Zirconia implant abutments: a review. Med Oral Patol Oral Cir Bucal 2011;16(1): 50-55.
3. Atsü SS, Aksan E, Bulut AC. Fracture Resistance of Titanium, Zirconia, and Ceramic-Reinforced Polyetheretherketone Implant Abutments Supporting CAD/CAM Monolithic Lithium Disilicate Ceramic Crowns After Aging. International Journal of Oral & Maxillofacial Implants 2019;34(3):622-630.
4. Türksayar AA, Atsü SS. Fracture Resistance of Zirconia, Polyetheretherketone, and Polyetherketoneketone Implant Abutments After Aging. International Journal of Oral & Maxillofacial Implants 2021;36(2):332-340.
5. Jitwirachot K, Rungsiyakull P, Holloway JA, Jia-Mahasap W. Wear Behavior of Different Generations of Zirconia: Present Literature. International Journal of Dentistry 2022;2022:1-17.
6. Alexakou E, Damanaki M, Zoidis P, Bakiri E, Mouzis N, Smidt G, Kourtis S. PEEK high performance polymers: A review of properties and clinical applications in prosthodontics and restorative dentistry. Eur. J. Prosthodont. Restor. Dent 2019;27:113-121.
7. Paratelli A, Perrone G, Ortega R, Gómez-Polo M. Polyetheretherketone in Implant Prosthodontics: A Scoping Review. International Journal of Prosthodontics 2020;33(6):671-679.
8. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials 2007;28(32):4845-4869.
9. Elsayed A, Farrag G, Chaar MS, Abdelnabi N, Kern M. Influence of Different CAD/CAM Crown Materials on the Fracture of Custom-Made Titanium and Zirconia Implant Abutments After Artificial Aging. The International Journal of Prosthodontics 2019;32(1):1-96.
10. Yazigi C, Kern M, Chaar MS, Libecki W, Elsayed A. The influence of the restorative material on the mechanical behavior of screw-retained hybrid-abutment-crowns. Journal of the Mechanical Behavior of Biomedical Materials 2020;111:103988.
11. Neumann EA, Villar CC, França FM. Fracture resistance of abutment screws made of titanium, polyetheretherketone, and carbon fiber-reinforced polyetheretherketone. Brazilian oral research 2014;28:1-5.
12. Chun KJ, Lee JY. Comparative study of mechanical properties of dental restorative materials and dental hard tissues in compressive loads. Journal of dental biomechanics 2014;5:1-6
13. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. Journal of prosthodontic research 2016;60(1):12-19.
14. Mohamed S, Shamaz BH. Bone tissue engineering and bony scaffolds. Int. J. Dent. Oral Health 2015;1:15-20.
15. Tangsatchatham S, Juntavee N. Flexural strength of various types of computerized machinable ceramic veneered to yttria stabilized tetragonal zirconia polycrystalline ceramic upon different hybridized techniques. Clinical, Cosmetic and Investigational Dentistry 2019;11:61-71.
16. Iyer RS, Suchitra SR, Hegde D, Coutinho CA, Priya A. BioHPP: Properties and applications in Prosthodontics a Review. Journal of Research in Dentistry 2020;7(4):72-76.
17. Yan Y, Jiang C, Huo Y, Li C. Preparation and tribological behaviors of lubrication-enhanced PEEK composites. Applied Sciences 2020;10(21):7536.
18. Ibrahim A, Magliulo N, Groben J, Padilla A, Akbik F, Abdel Hamid Z. Hardness, an important indicator of bone quality, and the role of collagen in bone hardness. Journal of Functional Biomaterials 2020;11(4):85.
19. Abd El-Fattah A, Youssef H, Gepreel MA, Abbas R, Kandil S. Surface morphology and mechanical properties of polyether ether ketone (PEEK) nanocomposites reinforced by nano-sized silica (SiO2) for prosthodontics and restorative dentistry. Polymers 2021;13(17):3006.
20. Al-Zordk W, Elmisery A, Ghazy M. Hybrid-abutment-restoration: effect of material type on torque maintenance and fracture resistance after thermal aging. International Journal of Implant Dentistry 2020;6(1):1-7.
21. Rosentritt M, Rembs A, Behr M, Hahnel S, Preis V. In vitro performance of implant-supported monolithic zirconia crowns: Influence of patient-specific tooth-coloured abutments with titanium adhesive bases. Journal of dentistry 2015;43(7):839-845.
22. Elsayed A, Yazigi C, Kern M, Chaar MS. Mechanical behavior of nano-hybrid composite in comparison to lithium disilicate as posterior cement-retained implant-supported crowns restoring different abutments. Dental Materials 2021;37(8):435-442.
23. Santing HJ, Meijer HJ, Raghoebar GM, Özcan M. Fracture strength and failure mode of maxillary implant?supported provisional single crowns: a comparison of composite resin crowns fabricated directly over PEEK abutments and solid titanium abutments. Clinical implant dentistry and related research 2012;14(6):882-889.
24. Antônio Barbosa-Júnior S, Rocha Pereira GK, Serafini Dapieve K, Soares Machado P, Felipe Valandro L, Schuh C, Xediek Consani RL, Bacchi A. Mechanical Fatigue Analysis of PEEK as Alternative to Zirconia for Definitive Hybrid Abutments Supporting All-Ceramic Crowns. International Journal of Oral & Maxillofacial Implants 2020;35(6):1209-1217.
25. Silthampitag P, Chaijareenont P, Tattakorn K, Banjongprasert C, Takahashi H, Arksornnukit M. Effect of surface pretreatments on resin composite bonding to PEEK. Dental materials journal 2016;35(4):668-674.
26. Kaleli N, Sarac D, Külünk S, Öztürk Ö. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: A three-dimensional finite element analysis study. The Journal of prosthetic dentistry 2018;119(3):437-445.
27. Huang ZL, Shi JY, Zhang X, Gu YX, Lai HC. The influence of the shock-absorbing restorative materials on the stress distributions of short dental implant rehabilitations. European Review for Medical and Pharmacological Sciences 2021;25(1):24-34.
28. Tekin S, Değer Y, Demirci FA. Evaluation of the use of PEEK material in implant-supported fixed restorations by finite element analysis. Niger J Clin Pract 2019;22(9):1252-1258.
29. Bataineh K, Al Janaideh M. Effect of different biocompatible implant materials on the mechanical stability of dental implants under excessive oblique load. Clinical implant dentistry and related research 2019;21(6):1206-1217.
30. Mourya A, Nahar R, Mishra SK, Chowdhary R. Stress distribution around different abutments on titanium and CFR-PEEK implant with different prosthetic crowns under parafunctional loading: A 3D FEA study. Journal of Oral Biology and Craniofacial Research 2021;11(2):313-320.
31. Schwitalla AD, Abou-Emara M, Spintig T, Lackmann J, Müller WD. Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone. Journal of biomechanics 2015;48(1):1-7.
32. Pumnil S, Rungsiyakull P, Rungsiyakull C, Elsaka S. Effect of Different Customized Abutment Types on Stress Distribution in Implant?Supported Single Crown: A 3D Finite Element Analysis. Journal of Prosthodontics 2022;31(5):2-11.
33. Suphangul S, Rokaya D, Kanchanasobhana C, Rungsiyakull P, Chaijareenont P. PEEK Biomaterial in Long-Term Provisional Implant Restorations: A Review. Journal of Functional Biomaterials 2022;13(2):33.
34. Poovarodom P, Rungsiyakull C, Suriyawanakul J, Li Q, Sasaki K, Yoda N, Rungsiyakull P. Effect of implant placement depth on bone remodeling on implant-supported single zirconia abutment crown: A 3D finite element study. Journal of Prosthodontic Research 2022:JPR_D_22_00054.
35 Tretto PH, Dos Santos MB, Spazzin AO, Pereira GK, Bacchi A. Assessment of stress/strain in dental implants and abutments of alternative materials compared to conventional titanium alloy—3D non-linear finite element analysis. Computer Methods in Biomechanics and Biomedical Engineering 2020;23(8):372-383.
36. Akça KI, Iplikçioğlu H. Finite element stress analysis of the effect of short implant usage in place of cantilever extensions in mandibular posterior edentulism. Journal of oral rehabilitation 2002;29(4):350-356.
37. Tamrakar SK, Mishra SK, Chowdhary R, Rao S. Comparative analysis of stress distribution around CFR-PEEK implants and

titanium implants with different prosthetic crowns: a finite element analysis. Dent Med Probl 2021;58:359-367.
38. Taha D, Sabet A. In vitro evaluation of material dependent force damping behavior of implant-supported restorations using different CAD-CAM materials and luting conditions. The Journal of Prosthetic Dentistry 2021;126(1):1-9
39. Duyck J, Vandamme K. The effect of loading on peri-implant bone: a critical review of the literature. J Oral Rehabil 2014;41(10):783-794.
40. Cantó-Navés O, Medina-Galvez R, Marimon X, Ferrer M, Figueras-Álvarez Ó, Cabratosa-Termes J. A 3D finite element analysis model of single implant-supported prosthesis under dynamic impact loading for evaluation of stress in the crown, abutment and cortical bone using different rehabilitation materials. Materials 2021;14(13):3519.
41. Preis V, Hahnel S, Behr M, Bein L, Rosentritt M. In-vitro fatigue and fracture testing of CAD/CAM-materials in implant-supported molar crowns. Dental Materials 2017;33(4):427-433.
42. Donmez MB, Diken Turksayar AA, Olcay EO, Sahmali SM. Fracture Resistance of Single?Unit Implant?Supported Crowns: Effects of Prosthetic Design and Restorative Material. Journal of Prosthodontics 2022;31(4):348-55.
43. Schwitalla AD, Abou-Emara M, Zimmermann T, Spintig T, Beuer F, Lackmann J, Müller WD. The applicability of PEEK-based abutment screws. Journal of the mechanical behavior of biomedical materials 2016;63:244-251.
44. Chen X, Ma R, Min J, Li Z, Yu P, Yu H. Effect of PEEK and PTFE coatings in fatigue performance of dental implant retaining screw joint: An in vitro study. Journal of the Mechanical Behavior of Biomedical Materials 2020;103:103530.
45. Stimmelmayr M, Lang A, Beuer F, Mansour S, Erdelt K, Krennmair G, Güth JF. Mechanical stability of all-ceramic abutments retained with three different screw materials in two-piece zirconia implants—an in vitro study. Clinical Oral Investigations 2020;24(5):1801-1806.
46. Tammam R, Abuzinadah SH, Alhaddad AJ, Mortada A. Clinical, Technical, and Esthetic Performance of Different Ceramic Materials Crown on Posterior Single Implant-Supported Restorations: Prospective Clinical Study 3 Years. Journal of International Dental and Medical Research 2021;14(3):1064-1072.
47. Renzo G, Di Nardo D, D'Angelo M, Seracchiani M, Miccoli G, Testarelli L. Peri-Implant Marginal Bone Changes and Soft Tissue Conditions around Single Implants with Laser-Microgrooved Collar Placed in Regenerated Extraction Sockets and in Native Bone: 2-Year Results of RCT. Journal of International Dental and Medical Research 2020;13(1):275-282.