Review Article

The Application of Polyether Ether Ketone as Post and Core: A Systematic Review

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Abstract

Background: Various studies reveal that the elastic modulus of the Polyether Ether Ketone (PEEK) material is very close to dentin tissue; thus, less stress formation occurs in the tooth, and post-core restoration compared to other post systems was observed. In this context, PEEK post may reduce irreversible complications. PEEK is a new invention with a wide area of application in dentistry. The aim of the systematic review is to compile studies that focus exclusively on the mechanical properties, advantages, modifications of the PEEK material used as post and core material. **Materials & Methods:** This review was conducted using the electronic search from 2011 and 2021 by various databases like PubMed (Medline), Science Direct, Cochrane library, Embase Wiley online library, and the Web search Google Scholar, using keywords like Post/posts, dowel/dowels, post and core, dowel and core with Polyether ether ketone or PEEK. The search was limited to articles published as full text in English, which were screened by two reviewers for eligibility. **Results:** All twelve eligible studies suggested PEEK as a reliable and contemporary option for dental post systems when used with appropriate surface treatment and luting agent. Significant reduction in the stress generated on the periodontal ligament (PDL) and cortical bone was observed when PEEK posts were used. **Conclusion:** PEEK post and core showed promising results with good mechanical and bonding properties. It can prove to be a successful alternative material to be used in clinical practice. However, clinical studies are lacking and more *in-vitro* and *in-vivo* studies are still needed to evaluate PEEK as post and core material.

Keywords: Polyether Ether Ketone; Post and Core; Endodontics; Teeth

Introduction

Various post and core materials are available for treating endodontically mutilated teeth. However, selecting appropriate material and technique of post and core is still a dilemma in dental practice. [1-3] The selecting criteria are based on the tooth's position, remaining tooth structure, the material of core and crown, root canal anatomy, and preferences of patient and dentist. [4,5] Various forms of posts are available in the market. The commercially available post is known as prefabricated post, whereas laboratory fabricated post is known as custom post, available as one-piece post and core. [6,7] Metal post is one of the most widely used posts for a long time, but it has various disadvantages. To overcome these drawbacks, various other materials came into advent. [8] The metal post's unaestheticappearance was overcome with the emergenceof translucentall-ceramic crown materials. However, these crown materials have disadvantages of corrosion, unfavourable catastrophic tooth fracture, low bonding quality, and high modulus of elasticity that have constrained dental practitioners for other materials.

Glass fiber postis the most commonly used prefabricated post due to its colour, low modulus of elasticity, good bonding, resistance to corrosion, and favourable tooth fracture after failure. Due to lower modulus of elasticity, glass fiber post transmitslesserstress than metal post. However, the modulus of fiber post elasticityis higher (45.7–53.8 GPa) than dentin (18.6 GPa). [9-11] Furthermore, bond strength of glass post is less that can lead to microleakage and post failure. [12]

Polyether ether ketone (PEEK) is a relatively new material in dentistry, introduced in 1992. [13] It is a polycyclic, linear, aromatic, high molecular, semi-crystalline thermoplastic polymer that is procured by step-growth polymerizationby binding ketone and ether functional groups between them aryl rings. [14,15]

It has excellent biocompatibility and compelling mechanical and chemical properties. [16-18] Because of its good thermal and chemical stability, it can withstand the sterilization process. [19-21]The elastic modulus is around 3-4 GPa and this reduces forceconcentration that is transferred to dentin and uniformly distributes stresses. [22] PEEK is a white-opaque translucent material with better esthetic properties than metal-based materials. [23] It is used for dental implant body, implant abutment, fixed dental prosthesis,removable partial denture, and orthodontic wires. [24] Another application ofPEEK is dental post and core. Various studies have been conducted on evaluating PEEK as post and core material.

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Thus, this current literature review aims to summarize the studies conducted in relation to PEEKas post and core.

Materials and Methods

The electronic search was carried out using data published from 2011 to 2021 by the following databasesPubMed (Medline), Science Direct, Cochrane library, Embase Wiley online library, and Web search Google Scholar. Keyword used for the search was: Post/posts, dowel/dowels, post and core, dowel and core with Polyether Ether Ketone or PEEK. The inclusion criteria applied were: 1) Articles related to PEEKor modified PEEK, 2) Articles related to post, dowel, post, and core or dowel core, 3) articles publishedin the last 10 years, 4) articles written in the English language. Figure 1 shows that the initial computerized search strategy yielded 202 titles. In the first selection two reviewers with ten years' experience in the field, screened the articles by reading titles and abstracts of the retrieved publications and 146 were discarded because these articles did not fulfil the inclusion criteria. Any conflicting views were resolved by mutual discussion between reviewers. Out of those 56 articles, 29 were excluded as these were review articles and were not published in English. Remaining 80 articles that fulfilled the eligibility criteria were read in full. Among these 27 articles, 15 were excluded due to lack of adequate data and discrepancy in outcome, only 12 studies met our inclusion criteria. Later, each reviewer performed screening of eligible articles individually and tried to obtain the full text of final eligible studies for this systematic review.

On the basis of studies characteristics (title of the paper, author's information, year of study, aim and objectives, sample, outcome, and conclusion) two reviewers' independently extracted data using the standard data extraction form. Studies focusing on the use of PEEK as post and core were analysed for bias by the reviewers. Differences between the reviewers were sorted out by mutual discussion.

Results

The database search found a total of 202 articles. Out of which, twelve articles matched the criteriaand were included in the present review. The types of articles included were: 10 in-vitro studies, one case report, and one laboratory study. The studies included were stress and strain distribution, fracture resistance, surface roughness, tensile and push-out bond strength, fracture load and flexural strength, restorative retention force, and fabrication method. All studies suggested polyether ether ketone (PEEK) as a reliable and contemporary option for dental post systems when used with appropriate surface treatment and luting agent [Table 1]. Moreover, it has been found to possess superior mechanical, chemical, thermal, and esthetical properties with low risk of fracture. The stress value on PDL was 43091 MPa in the PEEK post and metal-ceramic crown group; and 43211 MPa for the PEEK post and crown group. The stress observed in dentin, when carbon fibre reinforced CFR-PEEK post used was lesser in comparison to

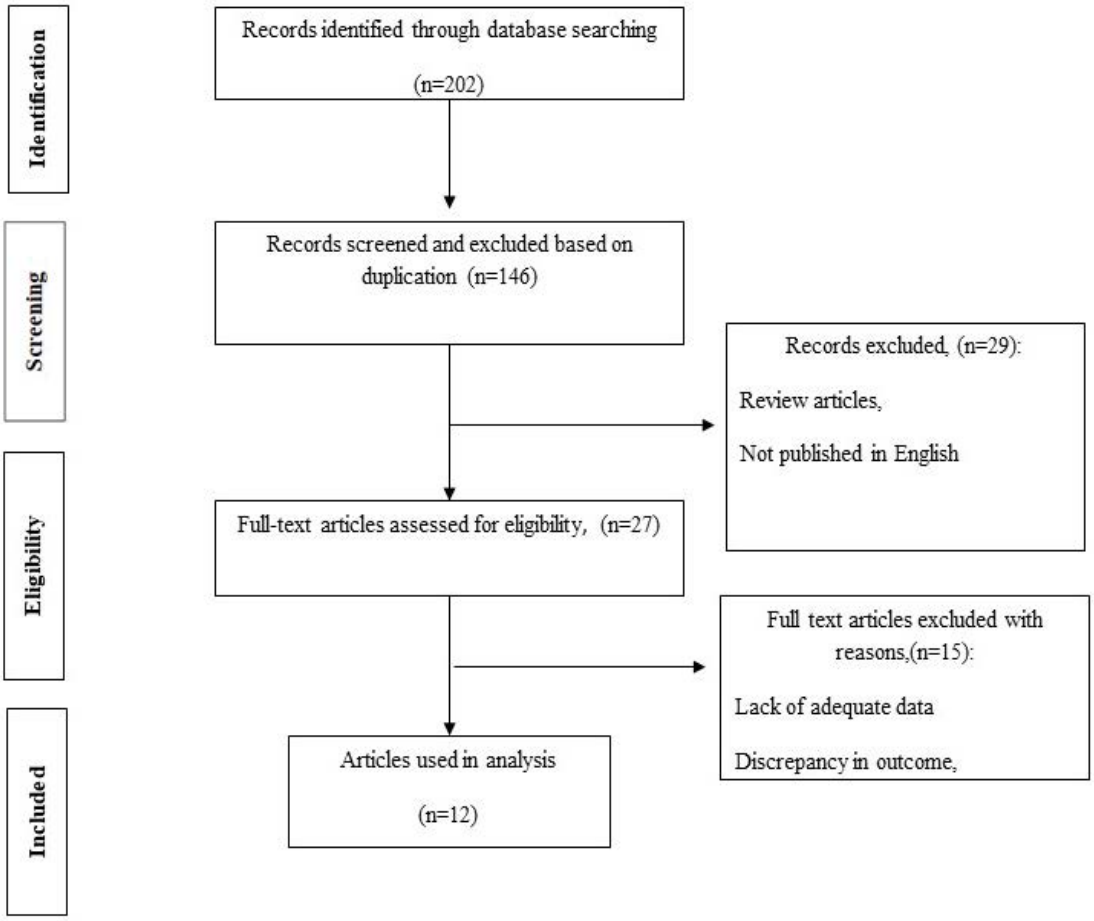

Figure 1: PRISMA flow chart.

Table 1: Summarizes studies from pre-existing literature pertaining to Polyether Ether Ketone (PEEK) as post and core.

Author (Year)	Aim and Objectives	Sample	Results	Conclusion
Tiwari A et al. [5]	Introduction of Biocompatible high-performance polymers, polyetheretherketone (PEEK)	Maxillary central Incisor	PEEK has higher fracture resistance, shock-absorbing ability,and better stress distribution	PEEK could be considered as an alternative dental material for metal and glass ceramics
Benli M et al. [16]	To test polyetheretherketone (PEEK) as a dental post material through tensile bond strength (TBS) and surface roughness (SR), and to compare it with glass-fiber and cast-metal posts.	60 endodontically treated maxillary central incisor Three groups (n = 20) according to the type of post (Group P: PEEK, Group F: Glass-fiber, Group M: Cast-metal).	Group F demonstrated the highest SR (2.93 ± 0.18 μm) and lowest TBS values (10.05 ± 0.53 MPa), while group P exhibited lowest SR (1.37 ± 0.11 μm) and highest TBS values (14.33 ± 0.58 MPa) ($p < 0.001$). No significant differences in failure modes were identified among groups, mostly adhesive ($p = 0.243$).	PEEK may be a reliable and contemporary option for dental post systems when used with appropriate surface treatment and luting agent. This high-performance polymer may be a novel candidate as a contemporary dental post system due to its superior mechanical, chemical, thermal, and esthetical properties with low risk of fracture.
Tekin S et al. [25]	To evaluate the stress distribution on the crown, surrounding cortical bone, and periodontal ligament (PDL) using the Micro-CT scan model on maxillary central incisor by intermittent application of PEEK post, fiber post, metal-ceramic crown, and PEEK crown	Maxillary Central Incisor	There was a reduction in the stress generated on the PDL and cortical bone when PEEK posts were used. The stress value on PDL was 43091 MPa in the PEEK post and metal-ceramic crown group; and 43211 MPa for the PEEK post and crown group. The stress value on cortical bone was 30168 MPa for the PEEK post and Metal ceramic crown group; 30219 MPa for the PEEK post and crown group.A reduction in stress values was observed on the crowns when PEEK material was used regardless of the post material	The reduction in the stress is because of the lower elastic modulus of PEEK material (3-4 GPa) than the other materials. The use of PEEK crown reduced the stresses occurring on the crown and increased the stresses occurring on the PDL and cortical bone and could be used routinely in dentistry
Sammany F et al. [27]	To evaluate the mechanical behaviour of a single endodontically treated tooth used with a PEEK post, carbon fiber reinforced PEEK (CFR-PEEK) post, metal cast post, and a sound tooth	Four three dimensional models of maxillary central incisor were made by Solid Works 2017 (SP 2.0 premium) software	The system of PEEK post showed the highest stress-concentration in adhesive cement layer, whileCFR-PEEK post showed the best stress distributionin adhesive cement layer. because of the elastic modulus of CRF-PEEK (18 GPa) being in close proximity to both the adhesive layer and dentine.	No systems of post and core threatened the safety of the dentin under the regular physiological occlusal forces. PEEK post showed the highest stressconcentration in adhesive cement layer
Nahar R et al. [28]	To evaluate the stress distribution in an endodontically treated tooth with with four different post materialscarbon fiber reinforced (CFR-PEEK, Glass fiber reinforced PEEK (GFR-PEEK), and polyether ketone (PEKK)) and two different crowns (Metal ceramic and PEEK)	Eightthree dimensionalmodels of maxillary central incisor	Resin core with CFR-PEEK expressed the lowest stress value among the other posts under both vertical and oblique loads. The maximum stress was found in the CFR-PEEK post and the minimum in the PEKK post under both vertical and oblique loads and regardless of the crown type. The stress on dentin was the lowest in CFR-PEEK regardless of the crown type for both oblique and vertical loads.	Stress observed in dentin, when CFR-PEEK post was used was lesser, PEEK crown and the PFM crown showed similar effect in dentin in stress generation. Hence, PEEK crown can be used as an alternative to the PFM crown.
Ibrahim RO et al. [29]	To analyze the mechanical and thermal behaviour of prefabricated PEEK posts having different post head designs	Three-dimensional surface model of maxillary central incisor	Prefabricated PEEK post with a spherical head has less stress in the composite core material. PEEK posts exhibited more stress distribution than titanium and fiber posts and PEEK produced less thermal gradient than fiber post, leading to lesser post-loss over time.	A proper design of the post head produces a more benign stress distribution and minimizes the risk of failure after post-endodontic treatment. Endodontically treated teeth restored with PEEK prefabricated posts may survive masticatory and oral thermal loading stresses better than titanium and glass fiber post. PEEK prefabricated post, exhibited a favourable stress distribution pattern at the intra-radicular dentin, indicating a lower possibility of vertical root fracture than

				stiffer post materials. Glass fiber post produced the highest temperature gradient between components of the restored tooth model, followed by PEEK post
AlQahtani M [30]	To evaluate the push-out strength of custom-made CAD/ CAM PEEK posts	Forty custom made PEEK endodontic posts20; modified with 50 µmaluminum oxide air-abrasion and 20 with 98% sulfuricacid etching , and 10 used as controls	Results showed that applying a surface treatment with separate bonding agents significantly improved the bond strength. Push-out bond strength was greater in the combined surface modification of air-abrasion and scotch bond at 10.884 N. The acid etching with sulfuric acid and Monobond plus surface treatment showed less bond strength at 8.861 N. The bond strength in control groups was significantly lower at 5.992 N.	PEEK is a thermoplastic material with low surface energy that causes the surface modification critical. However, applying sulfuric acid or sandblasting effectively increases the bond strength
Alawar MAR [34]	To evaluate the fracture resistance of endodontically treated teeth with custom made CAD/ CAM PEEK post and core compared to CAD/ CAM PEEK endo crown	Forty mandibular premolar teeth Group I: Twenty mandibular premolar teeth restored with customized CAD-CAM Post-core. Group II: Twenty mandibular premolar teeth restored with customized Endocrown. Each group was fabricated from Polyetherether Ketone (PEEK) material.	There was a statistically significant difference was detected between PEEK Post-core with higher mean value than Endo crown design 1863.24 & 1566.87respectively	Fracture resistance load obtained in different design restoredby PEEK Post-core treated mandibular premolar demonstrated significant greater failure resistance than Endocrown design
Teixeira KN et al. [36]	To evaluate the fracture resistance and failure mode of custom-made post-and-cores manufactured with different esthetic materials.	48 extracted endodontically treated mandibular premolar teeth Four groups (n=12/group): group1, polyetheretherketone (PEEK, Degos; G1); group 2, nano-ceramic composite (Lava Ultimate, 3M ESPE; G2); group 3, cast metal post (NiCr alloy, control; G3); group 4, fiberglass post (Whitepost, FGM, control; G4) customized with a nano-hybrid resin composite (Z250, 3M ESPE	The fracture resistance values (mean ± SD, in newtons) were 379.4 ± 119.8 (G1), 506.4 ± 138 (G2), 939.6 ± 146.5 (G3), and 449.6 ± 66.5 (G4). Only G3 exhibited a significant difference ($p<0.05$)	Customized post-and-cores of PEEK and nano-ceramic composites exhibited good mechanical performance. Their fracture resistance was comparable to that observed for fiberglass customized posts, yet lower than that for cast metal posts.
Sugano K et al. [37]	To use polyetheretherketone (PEEK) for the post material and evaluate the fracture load of six restorationpatterns in teeth with flared root canals	60 extracted mandibular incisors with flared root canals Six restoration Patterns were analyzed; divided into groups composite resin core alone (Group R); glass fiber sleeve (Group S); PEEK post (Group P); glass fiber post (Group F); PEEK post in glass fiber sleeve (Group PS);and glass fiber post in glass fiber sleeve (Group FS)	In the bending test, groups using glass fiber postsand sleeves decreased in strength after water immersion.In the loading test, Groups F, FS and PS showed higher fracture load.	PEEK posts and glass fiber sleeves should recommended in the case of flared root canals
Haralur SB [39]	To test the fracture resistance of endodontically treated teeth (ETT) restored with different esthetic post materials like fiber-reinforced composite post (FRC), polyether ether ketone (PEEK), and polymer infiltrated ceramic (PIC)	Thirty-six human root canal treated single-rooted premolar teeth Three groups (n= 12) to be restored with FRC, PEEK, and PIC	PEEK post had the maximum fracture load (1929.94 N), followed by PIC endodontic post group (1810.65N), and FRC post (1715.68N)	PEEK endodontic post displayed higher fracture resistance.
Li P et al. [40]	To evaluate retentive characteristics of the PEEK post-core restoration with-Poly vinyl siloxane (PVS) attachment systems.	10 specimens of PVS attachments with three different degrees of Shore hardness denoted as SH25, SH50, and SH65, respectively and PEEK post-core restoration (n = 8 per groups) were used	Strong negative linear relationship between the cyclic times and retention force ($p < 0.0001$, $r = -0.957$) was observed. The retention forces of the PVS were significantly improved with Shore hardness increased, which was affected by the aging treatment ($F (2, 138) = 10.95$, $p < 0.0001$).	PEEK post-core restoration with PVS attachments exhibited the favorable retention force, which could be a promising alternative for dental prostheses.

Table 2: Shows risk of bias assessment across individual studies.

First Author (Year)	Randomization Sequence	Allocation Concealment	Blinding of Participants	Blinding of outcome assessment	Incomplete Outcome data
Tiwari A et al. [5]	_	+	+	+	_
Benli M et al. [16]	_	+	+	+	_
Tekin S et al. [25]	_	+	+	+	_
Sammany F et al. [27]	_	+	+	+	_
Nahar R et al. [28]	_	+	+	+	_
Ibrahim RO et al. [29]	_	+	+	+	_
AlQahtani M [30]	_	+	+	+	_
Alawar MAR [34]	_	+	+	+	_
Teixeira KN et al. [36]	_	+	+	+	_
Sugano K et al .[37]	_	+	+	+	_
Haralur SB [39]	_	+	+	+	_
Li P et al. [40]	_	+	+	+	_

(+) High Risk and (−) Low Risk Bias

porcelain fused metal (PFM) crown, hence PEEK crown can be used as an alternative to the PFM crown. In support of this finding, the proper design of the post head produces a more benign stress distribution and minimizes the risk of failure after post-endodontic treatment. PEEK prefabricated post exhibited a favourable stress distribution pattern at the intra-radicular dentin, indicating a lower possibility of vertical root fracture than stiffer post materials.

When fracture resistance of materials was studied, customized post-and-cores of PEEK and nano-ceramic composites showed good mechanical performance. The fracture resistance values (mean ± SD, in newtons) for PEEK (379.4 ± 119.8), and nano ceramic composite (506.4 ± 138) were comparable, but was lower thancast metal post (939.6 ± 146.5). By our analysis of twelve studies, PEEK is a promising dental material for endodontic post and core attributed due to strong mechanical and bonding properties. Table 2 shows that all included studies demonstrated low risk bias using COCHRANE BIAS TOOL. All studies showed low risk bias for randomization whereas high risk bias was found for allocation concealment and blinding of participants. No inadequacy towards outcome data was observed for all studies

Discussion

Polyether Ether Ketone (PEEK) is one of the fast-growing materials being used in the dental practice. Demand for a metal-free material with good physical and chemical properties has led to the introduction of PEEK material in different dentistry areas. The use of PEEK as post and core material is a recent application. Various research studies are being conducted in this field. According to the data available, the first clinical application of PEEK as post and core was in 2018, published as a case report. In this case report, a milled PEEK post and core was fabricated and cemented with dual-polymerized resin cement after etching post with 98%sulfuric acid for 60 second.

Tekin et al. [25] conducted a finite element study to evaluate the stress distribution on the crown, surrounding cortical bone, and Periodontal Ligament (PDL) using the Micro-CT scan model of the maxillary central incisor. PEEK post, fiber post, metal-ceramic crown, and PEEK crown were interchangeably applied. There was a reduction in the stress generated on the PDL and cortical bone when PEEK posts were used. The stress value on PDL was 43091 MPa in the PEEK post and metal-ceramic crown group; and 43211 MPa for the PEEK post and crown group. The stress value on cortical bone was 30168 MPa for the PEEK post and Metal ceramic crown group; 30219 MPa for the PEEK post and crown group. A reduction in stress values was observed on the crowns when PEEK material was used regardless of the post material. This reduction in the stress is because of the lower elastic modulus of PEEK material (3-4 GPa) than the other materials. This significant effect was observed on the force transmission and distribution as the material acts as a force absorber. [26]

In another finite element study, the mechanical behaviour of a single endodontically treated tooth used with a PEEK post, carbon fiber reinforced PEEK (CFR-PEEK) post, metal cast post, and a sound tooth was evaluated. The study revealed that PEEK and CFR-PEEK posts showed similar mechanical behaviour and stress distribution. Also, CFR-PEEK showed a better stress distribution on the adhesive cement layer. [27] This might be because of the elastic modulus of CRF-PEEK (18 GPa) being in close proximity to both the adhesive layer and dentine.

Nahar et al. [28] performed a finite element study to evaluate the stress distribution in an endodontically treated tooth with four different post materials (CFR-PEEK, Glass fiber reinforced PEEK (GFR-PEEK), and polyether ketone (PEKK)) and two different crowns (Metal ceramic and PEEK). Resin core with CFR-PEEK expressed the lowest stress value among the other posts under both vertical and oblique loads. The maximum stress was also found in the CFR-PEEK post and the minimum in the PEKK post under both vertical and oblique loads and regardless of the crown type. Furthermore, the stress on dentin was the lowest in CFR-PEEK regardless of the crown type for both oblique and vertical loads. While applying oblique force, the stress was generated at the facial aspect of root canal dentin, especially at the coronal third. However, CFR-PEEK exhibited less stress concentration on the coronal part compared to fiber post and GFR-PEEK. This is due to the high rigidity of the CFR-PEEK post, which distributes stress more than flexible posts, thus decreasing the chance of the post and core failures.

Furthermore, another finite element study was conducted to

analyze the mechanical and thermal behaviour of prefabricated PEEK posts having different post head designs. [29] The study concluded that the prefabricated PEEK post with a spherical head has less stress in the composite core material. This is due to the lack of stress concentration area in the sharp edge compared to the non-head, cubical and conical head prefabricated PEEK post. PEEK posts exhibited more stress distribution than titanium and fiber posts. This agrees with the previous studies, which was explained by the close elastic modulus of the PEEK post to the dentin that causes less post system failure. The authors also observed that PEEK produced less thermal gradient than fiber post, leading to lesser post-loss over time, which was the main disadvantage of the fiber post system. In addition, the study concluded that there was no significant difference of stresses on PDL between various post systems studied. This specific result was in disagreement with the previous studies, and the differences might be due todifferent parameters used in the different finite element studies.

Regarding the PEEK post's bonding properties, there were only two studies that evaluated the bond strength of the PEEK post. AlQahtani et al. [30] evaluated the push-out strength of custom-made CAD/CAM PEEK posts. Different test groups were tested with or without surface treatment (etching with 98% of sulfuric acid, sandblasting with alumina Oxide (AlO_3) of 50 µm) of post used. Separate bonding agents were applied on the surface treated posts, and no aging process was performed. Then all the posts were cemented with self-adhesive resin cement. The study showed that applying a surface treatment with separate bonding agents significantly improved the bond strength. PEEK is a thermoplastic material with low surface energy thatcauses the surface modification critical. [31-33] However, applying sulfuric acid or sandblasting effectively increases the bond strength. Another study evaluated the surface roughness, surface characteristics, and tensile bond strength using different post systems after the aging process. Custom made CAD/ CAM PEEK post with 98% sulfuric acid etching, fiber post with 40% phosphoric acid, and cast metal post with alumina oxide (AlO3) of 50 µm sandblasting were used and compared in this study. It was observed that although PEEK showed the highest tensile bond strength, it exhibits the lowest surface roughness. The chemical and surface micro-geometry alterations of the PEEK surface after application of sulfuric acid etching significantly increase the surface energy and increase the concentration of the carbon-oxygen group of the superficial layer that improved the bonding properties.

Fracture resistance of endodontically treated teeth with post and core is one of the most critical parameters for selecting post material in clinical practice. Limited studies were conducted on PEEK as post and core material. A study was conducted to evaluate the fracture resistance of endodontically treated teeth with custom made CAD/CAM PEEK post and core compared to CAD/CAM PEEK endocrown. [34] The study revealed that the fracture resistance of PEEK post and core was significantly higher than endocrown. This could be due to the smaller adhesive area of the end crown compared to the post and core. [35] In another study, [36] CAD/CAM PEEK post and core exhibited comparable fracture resistance to fiber post and CAD/CAM non-ceramic composite post and core, which was in agreement with the previous study. [37] Also, failure modes were mostly repairable as fiber post and significantly better than the cast metal post and core. This is due to the low elastic of modulus of the PEEK post, which transfers the maximum stress above the bone level, and upon fracture, it produces a more favourable type of tooth fracture. [38]

In another study, endodontically treated teeth with PEEK post has slightly higher fracture resistance than fiber post and showed less favourable fracture mode. [39] This is due to the proximity of the elastic modulus of PEEK material to the dentin, more than fiber post to dentin. The main disadvantage of fiber posts was low bonding ability. This explains the mode of fracture, as the adhesive failure might happen first before fracture failure during the static load, and this will transfer the load more coronally that produce a favourable type of fracture. Li et al. conducted a study about the retentive characteristic of PEEK post and core as a matrix and polyvinyl siloxane (PVS) attachment as a patrix. [40] In this laboratory study, PEEK and PVS attachment system showed a promising result. However, the application of PEEK post and core for the attachment system for a removable dental prosthesis is still unclear.

Various studies on PEEK post and core reported an interesting and promising result that promotes this type of material as an excellent alternative to routine post and core materials. As there are limited in-vitro and in-vivo studies available on PEEK post and core, thus it is not easy to draw a definitive conclusion about using this material in clinical practice. There are many suggested areas of studies that are required regarding PEEK post and core like radiopacity, bonding proprieties, microleakage, cyclic fatigue resistance, flexural strength, light transmission, direct core material bonding to PEEK post, fracture, resistance, bending strength, tensile strength, failure mode, effects of post design and diameter.

Conclusion

The present review revealed that the PEEK post and core showed promising results with good mechanical and bonding properties. It can prove to be a successful alternative material to be used in clinical practice. However, clinical studies are lacking, and more in-vitro and in-vivo studies are still needed to evaluate PEEK as post and core material.

Conflict of Interests

The authors declare that they have no conflict of interest.

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