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Peek applications in restorative dentistry: A comprehensive review os uses, advantages and future prospects

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Abstract
This comprehensive research delves into the various applications, advantages, and possible usage of Polyetheretherketone (PEEK) in restorative dentistry. The research highlights the complex demands of recovering teeth after endodontic treatment and highlights the need for materials that closely mimic the mechanical properties of native dentin and enamel. The analysis highlights the dynamic shifts in restorative dentistry by evaluating the unique qualities of traditional dental restorative materials like amalgam, gold alloy, and dental resin. By examining PEEK's physical and chemical properties, the analysis highlights the material's mechanical strength, resistance to plaque retention, and excellent biocompatibility. The development of PEEK via modifications, such as nano-TiO2/PEEK and BioHPP, which are purposefully created to get around constraints and improve mechanical strength, is investigated. The benefits of PEEK, such as its ease of milling and better fracture resistance, are highlighted, especially when it comes to the dental prosthesis production processes that involve injection and CAD-CAM milling. PEEK's adaptability and durability in particular applications, such as dental prostheses, post-core restorations, and endocrowns, are elaborated upon in further talks. PEEK's excellent elastic modulus, robust fracture resistance, and flexibility are highlighted in the paper's evaluation of the material in restorative dentistry. It recognizes limitations such as low fatigue resistance to bending and hydrophobic surfaces. The conclusion highlights PEEK's bright future, propelled by continuing research and developments in material science, and highlights the necessity of thorough clinical trials to reveal more about its complex benefits, drawbacks, and ideal uses for noteworthy restorative results.

Keywords: Nano-TiO2/PEEK, BioHPP, Polyetheretherketone, endocrowns, post-core restorations, restorative dentistry

Introduction

Human teeth are incredibly strong and flexible, which makes them useful for cutting, lacerations, and crushing food when mastication occurs [1]. Dental restoration technologies, such as ceramics, synthetic resins, and metals, have made great strides toward emulating the complex structure, exceptional mechanical performance, and biocompatibility of real teeth [2]. This article examines Polyetheretherketone's (PEEK) uses, benefits, and prospects in restorative dentistry, with an eye toward how it might be able to overcome the drawbacks of traditional dental materials.

Given the different roles that enamel and dentin play in mastication, dental therapies frequently aim to restore the combined activities of these materials [3]. High abrasion resistance is essential for enamel's fundamental function in food grinding, highlighting hardness as a crucial material attribute [4]. Dentin, on the other hand, needs mechanical characteristics, such as maximum stress, maximum strain, and elastic modulus, to absorb bite forces [5]. A dentin substitute should have mechanical qualities that are equivalent to or better than those of enamel, while any substance meant to replace enamel should have hardness values that are comparable to or lower than those of enamel [5, 6].

Challenges in restoring endodontically treated teeth

Vitality loss's effect on dentin characteristics has long made the restoration of teeth that have undergone endodontic treatment a difficult task [7]. When teeth lose their vitality, the dentin undergoes changes in its micro-hardness, modulus of elasticity, and fracture toughness, which makes restorative procedures more challenging. Additionally, loss of hard tissue from decay, fracture, or cavity preparation causes changes in the biomechanics of teeth [6]. Meeting these challenges requires the development of materials that can replace lost tooth structure and function.

Dental Restorative Materials

Selecting the right materials for dental restorations is essential to get the best possible clinical results in the field of restorative dentistry. Conventional dental restorative materials, such as dental resin, amalgam, and gold alloy, have unique characteristics that affect which uses they are appropriate for. Amalgam, which has been studied in research [8], has hardness ratings than enamel, which guarantees longevity but calls for taking biocompatibility and aesthetics into account. According to research [9], gold alloy has an elastic modulus that is similar to dentin's, which improves its capacity to effectively absorb bite forces. According to studies [8], dental resin is suitable for occlusal biting because it can withstand higher maximum strains and stresses than dentin and has hardness values that are typically higher than enamel. It is imperative to strike a balance between the best possible mechanical qualities, biocompatibility, and aesthetics, as several studies have shown [8, 10, 11]. Dental materials are changing, and new alternatives with advantageous qualities for restorative dentistry are being introduced by companies like Polyetheretherketone (PEEK), which was covered in a study [12]. This presents opportunities to overcome the drawbacks of using more conventional materials. In conclusion, clinicians must have a sophisticated understanding of the mechanical characteristics, biocompatibility, and aesthetic implications of dental restorative materials in order to make decisions that successfully restore teeth's form and function while meeting the biomechanical requirements of the oral environment.

Comparison of traditional dental materials

In order to avoid undue wear on natural teeth, traditional dental materials like amalgam, gold alloy, and dental resin have harder hardness ratings than enamel [8]. Dental resin and gold alloy have greater maximum strains and stresses than dentin, but amalgam has an elastic modulus that is comparable to that of dentin. In contrast, dentin has a lower elastic modulus than gold alloy, which increases stiffness for the absorption of bite force [9]. The material used in prosthetic dentistry should not only be biocompatible and aesthetically pleasing, but also have mechanical qualities appropriate for occlusal biting [10].

Bite forces and material properties

In prosthetic dentistry, the emphasis is on the crucial role that material qualities play, emphasizing the necessity of materials that can endure the transfer of stress during functional activities. Maximum biting force is a critical criterion that, as multiple studies have shown [13], demands prosthetic materials with the best initial fracture resistance to achieve positive results, especially in the posterior region. Research like [14] emphasize how important it is to consider material characteristics that match the biomechanics of natural teeth to guarantee the success of prosthetic interventions. When choosing the right restorative materials, it is important to consider how biting forces and material resilience interact [9, 13, 15]. Acknowledging these aspects is critical to the prosthetic dentistry landscape because it directs practitioners toward materials that, for long-term success in clinical applications, not only aesthetically match the natural dentition but also survive the dynamic challenges offered by masticatory pressures.

Introduction of PEEK as restorative material

In restorative dentistry, Polyaryletherketone (PEEK) represents a breakthrough [12]. This breakthrough is placed in the larger framework of dentistry's history, which has seen a shift from the use of traditional materials like metals, acrylics, and zirconia to the creation of polymers like PEEK for medical uses [12, 16, 17, 18]. PEEK, as reported in research [12] and [16], is a promising material for restorative procedures because of its excellent mechanical, physical, and biocompatible qualities. PEEK is a thermoplastic polymer that combines good mechanical and chemical resistance with remarkable machinability [12, 19]. High-performance polymer materials are increasingly important in dentistry research, as evidenced by their prominence [12], which may improve framework properties and lower rehabilitation costs. This represents a paradigm change in the investigation of restorative materials in dentistry and establishes PEEK as a competitive candidate with diverse qualities appropriate for a range of therapeutic uses.

Physical and chemical properties of peek

Polyaryletherketone (PAEK) has been a thermoplastic polymer with remarkable mechanical and chemical resistance since the 1980s. It has also shown remarkable machinability in the engineering industry. High-performance polymer materials have gained prominence in dentistry research due to their promising qualities, which have the potential to improve framework properties and lower rehabilitation costs [12, 19].

Chemical composition and family members

PAEK is classified as a semi crystalline thermoplastic polymer with a melting point of 370°C and a glass transition temperature of roughly 157°C. The PAEK polymer's ether and ketone groups affect stiffness and polarity, and they also affect the melting point and glass transition temperature. The two PAEK family members are Polyetheretherketone (PEEK), which stands for the ether-ether ketone monomer unit, and polyetherketoneketone (PEKK), which represents the ether ketone monomer unit [5].

Physical and chemical properties of PEEK and PEKK

Semicrystalline polymers, including PEEK and PEKK, have mechanical and physical properties like bone, and they have a high impact strength. Particularly noteworthy for its biocompatibility is PEEK. Up to 335.8°C, this white, radiolucent, and stiff material exhibits exceptional thermal stability. Its non-allergic nature, minimal affinity for plaque, and flexural modulus of 140-170 MPa are further characteristics. PEEK is nearly identical to human bone, enamel, and dentin, with a density of 1.32 g/cm³ and a thermal conductivity of 0.29 W/mK. It also has a Young's modulus of 3-5 GPa. Among materials, it stands out for its exceptional biocompatibility, non-toxicity, and resistance to hydrolysis. Comparing PEEK to PMMA and composites, it has the lowest solubility and water absorption values, strong chemical resistance to a variety of solvents, and outstanding tribological properties [19].

It is possible to account for a thorough overview of the Young's modulus and tensile strength for a variety of materials that are pertinent to dental applications. One well-known thermoplastic polymer that has been studied extensively in dental contexts is Polyetheretherketone (PEEK), which has a Young's modulus of 3 to 4 GPa and a tensile strength of 80 MPa [11]. The material's tensile strength rises to 120 MPa when carbon fiber reinforcement (CFR-PEEK) is added, and its Young's modulus also significantly increases to 18 GPa [20]. Cortical bone exhibits a Young's modulus of 14 GPa and a tensile strength ranging from 104 to 121 MPa when compared to normal tooth structures [21]. On the other hand, the often-used dental material polymethyl methacrylate (PMMA) exhibits a range of 48 to 76 MPa for its tensile strength and 3 to 5 GPa for its Young's modulus. Dentin and other natural dental tissues have tensile strengths of 104 MPa and Young's moduli of 15 GPa, respectively, whereas enamel has tensile strengths of 47.5 MPa and an extraordinarily high Young's modulus of 40 to 83 GPa [20]. In contrast, titanium, a material commonly used for dental implants, has a very high Young's modulus of 102 to 110 GPa and a significant tensile strength of 954 to 976 MPa [9, 20]. This comparative research helps in the design and selection of appropriate restorative and prosthetic components by offering insightful information about the mechanical characteristics of various dental materials.

Mechanical evaluation and applicability of PEEK in dentistry

Using the three-point bending test, Schwitalla evaluates the mechanical properties of PEEK and finds exceptionally high results for flexural strength. PEEK exhibits stability in the face of varying temperature fluctuations, confirming its suitability for use in dentistry and significantly exceeding the minimum strength necessary for plastic materials in dentistry. This implies that metal-free restorations may be available to patients, especially those who have bruxism or allergies [19].

Advantages in dentistry and tensile properties

PEEK's radiolucency helps prevent attrition of opposing natural teeth and reduces artifacts in magnetic resonance imaging. PEEK further displays biocompatibility and bio-stability, backed by the US FDA Drug & Device Master files. PEEK is a viable restorative material because of its tensile qualities, which are comparable to those of bone, enamel, and dentin, especially in terms of mechanical qualities [19].

Antimicrobial and Osseo integration of PEEK

Investigating Polyetheretherketone (PEEK) in dental materials has produced some fascinating findings about its Osseo integration and antibacterial capabilities. Significant antibacterial activity has been shown by the inclusion of nano-fluorohydroxyapatite into PEEK, indicating that this material may be useful in preventing bacterial adherence and plaque development. Furthermore, positive Osseo integration-promoting properties of the composite material have been demonstrated, suggesting a promising interaction with surrounding bone tissue. These results highlight the versatility of PEEK-based materials, emphasizing their potential for important aspects like antimicrobial resistance and integration with biological structures, in addition to offering mechanical strength. This makes them attractive options for a variety of dental applications [22].

Modification of peek

For more than 40 years, orthopaedics has used Polyetheretherketone (PEEK), a material with a long history in medicine that has gained popularity for its exceptional mechanical qualities and great performance. Researchers have been working to improve the mechanical properties, stress resistance, and aesthetics of this material by investigating different approaches, such as adding fibers or ceramics with a diameter of less than 0.5 µm to reinforce it. The elastic modulus of PEEK has been reported to be 3.6 GPa in documented data. When carbon fibers (CFR PEEK) are added, the modulus rises to an astounding 18 GPa, which is in close agreement with the modulus of 15 GPa found in cortical bone [23]. Strength, abrasion resistance, and veneering are all enhanced by BioHPP® (Bredent, UK), a partly crystalline PEEK reinforced with ceramic [24]. Further improving its qualities is the introduction of nano-TiO_2/PEEK, which combines PEEK with nanoparticles of titanium dioxide [23]. The strong fatigue resistance of CFR-PEEK, which has been used historically in spinal cages, fracture fixation, femoral prostheses, bone fixation screws, and different implants, makes it perfect for dental applications like maxillary obturator prostheses in patients with oral-nasal abnormalities [20]. The anti-microbial capabilities of nanoparticles, such as hydroxyfluorapatite (n-FHA), may inhibit the growth of bacteria and the formation of biofilms [23]. With its inventive formulations and reinforced variations, this adaptable polymer shows promise as an alternative to conventional metal implant materials in orthopaedics and dentistry.

Manufacturing process for dental prosthesis

Diverse manufacturing approaches

Two unique manufacturing procedures stand out in the field of dental prosthetics: the CAD-CAM procedure and the injection procedure. PEEK blocks with a computer-designed structure are milled using the CAD-CAM process, which provides homogeneity, quality, and unchangeable properties [2]. Specifically, PEEK is more millable than titanium, which makes it a desirable material to use when creating both fixed and removable prostheses [25].

Advantages of CAD-CAM milling with PEEK

Compared to Co-Cr or titanium, PEEK is easier to mill and polish, making it a more favourable material to utilize in CAD-CAM milling. This results in prostheses that are lightweight and non-allergic [2, 3]. Studies show that PEEK fixed dentures machined using CAD-CAM technology have better fracture resistance than dentures made of zirconia, alumina, or lithium disilicate glass-ceramic [1].

Disadvantages and surface modifications

PEEK has drawbacks despite its advantages, most notably an inert and weakly sticky hydrophobic surface [13]. Various methods such as acid etching, plasma treatment, and laser treatment have been investigated to improve adhesion; among these, sulfuric acid treatment has shown promise in raising surface polarity [26]. A viable surface modification technique for PEEK is plasma treatment, which makes use of gases such as argon, helium, oxygen, hydrogen, and nitrogen [23].

Marginal fit considerations

For dental prosthesis to be successful, the marginal fit is essential. Inlay retained fixed partial dentures (IRFPD) made with PEEK and Zirconia using CAD-CAM technologies were compared, and the results showed that differences smaller than 120 µm were considered clinically acceptable [27]. Furthermore, CBCT and stereomicroscope readings consistently showed better marginal fit accuracy in PEEK crowns when comparing PFM and PEEK crowns [7, 17].

Resistance to Plaque retention

Due to the use of nano-fluorohydroxyapatite particles to PEEK structures, PEEK exhibits resistance to bacterial plaque [9]. This feature helps to minimize soft tissue irritations, as does PEEK's low surface roughness (0.018 Nm Ra) [28, 29]. Thus, the features and functionality of dental prosthesis are greatly influenced by the choice of production techniques and material alterations. The application of PEEK in dentistry is still being refined by ongoing research and improvements, providing a promising path for future advancements.

Peek applications in endocrown

Endocrowns, which are adhesive restorations that are single monolithic and are bonded to endodontically treated teeth using resin cement, represent the idea of a cohesive "monoblock" in which all the parts function as one [12]. The selection of materials for endocrowns includes adhesive choices that facilitate adhesive bonding to tooth structures, such as resin composites, reinforced glass ceramics with zirconia, etchable ceramics (Feldspathic, Leucite, or Lithium disilicate based), or hybrid resin nanoceramics [2, 12]. However, the use of ceramics in endocrown construction is limited due to their intrinsic brittleness and high elastic modulus. Under this situation, BioHPP appears to be a good substitute because of its 4000 MPa elastic modulus, which is comparable to that of human bone and dentin [30]. It addresses a major issue with traditional ceramics by reducing the transfer of forces to the abutment teeth by its capacity to absorb functional stresses through deformation and cushion chewing forces. BioHPP offers a strong option for endocrown applications, with a maximum fracture resistance of up to 1200 Newtons [30].

An analysis using 3D finite elements on monolithic complete posterior crowns highlights how elastic modulus affects the distribution of stress. Higher elastic modulus materials concentrate more shear stress on the cement layer and more tensile stress on the crown intaglio surface, which may cause crown debonding [4]. In order to solve debonding problems, Zheng *et al.* 3D finite element study highlights the importance of elastic modulus in stress distribution and suggests PEEK's potential as a stress breaker with lower shear and tensile stress [31]. PEEK functions as a stress breaker and lessens forces applied to the abutment teeth by allowing stress absorption through deformation due to its low modulus of elasticity [4]. Notably, clinical findings support the use of a light-polymerized composite resin veneered over a pressed PEEK-based framework for single crowns or endocrowns, particularly where there are metal allergies, severely damaged or weak abutment teeth, or parafunctional habits [5].

Determining PEEK's applications requires an understanding of its mechanical properties. The biological and mechanical parameters of treatments are mostly determined by the elastic modulus, maximum resistance to breaking, bonding strength to cosmetic coatings, and polishing properties [6]. According to Hendrik J, *et al.*, PEEK elasticity modulus is around 4,000 MPa, which is comparable to human bone and offers sufficient resistance to fracture as well as chewing force dampening [32]. PEEK crowns were subjected to vertical stresses of up to 1200 N *in vitro* experiments by Nazari V, *et al.*, which showed the material's robustness and promise for safety when compared to other materials, particularly when used in three-piece bridges [25].

Consequently, PEEK shows promise as a material for endocrown applications because it provides a special set of mechanical qualities that overcome the drawbacks of conventional ceramics. Clinical data and ongoing research highlight its potential as a dependable substitute in restorative dentistry [33].

Peek applications in post-core restorations

A post-core system is frequently required for the restoration of the coronal area of a tooth that has undergone endodontic treatment, which is essential for long-term clinical success. Selecting the right material becomes crucial because a poor choice might result in severe fractures and possibly require tooth extractions [12]. Metal alloys, fiberglass, and zirconia have all been researched in the past; each has pros and cons. Metal alloys, while robust, may lead to galvanic corrosion, metallic taste, and allergic reactions, and demonstrate a substantial difference in elastic modulus (EM) compared to dentin, producing stress imposition on teeth [2].

Despite having a lower EM than metal, fiberglass still has problems with post debonding, which is the main reason for failures [30]. Recently developed zirconia provides mechanical strength, biocompatibility, and a variety of fabrication possibilities; but, because of its high EM, it raises concerns with root fracture [4]. Due to its advantageous characteristics, polyetherketoneketone (PEKK) becomes a compelling option for bespoke intraradicular dental post-core systems [5]. PEKK exhibits strong fracture resistance even though it has a much lower elastic modulus and flexural strength than metal and fiberglass [6]. Comparing PEKK to traditional post-core materials, stress distribution study shows a more favorable profile with PEKK, especially at the intraradicular surface, indicating a lower likelihood of root fracture. Its flexibility, however, raises the possibility of debonding and crown failure, highlighting the necessity of carefully analyzing application conditions [32].

A clinical report [25] describes the effective use of Polyetheretherketone (PEEK) for custom-made post and core in central incisors that have undergone endodontic treatment and are weaker. Produced using computer-aided design/ computer-aided manufacturing (CAD/CAM), the PEEK structure showed ideal fit, removing the requirement for core build-up and permitting a thinner cement coating. This case report highlights PEEK's promising potential for predictable and simplified treatments with a successful track record of five years [8], even though more clinical trials and *in vitro* studies are necessary to fully understand the benefits and limitations of PEEK in post and core manufacturing.

The mechanical characteristics and potential therapeutic effects of materials must be carefully considered when choosing post-core systems materials. The field is changing, and materials like PEKK and PEEK provide viable substitutes. However, there are unique factors to consider, which should direct their wise use in various clinical situations [5, 25].

Peek applications in dental prostheses

The first molar region exhibits the largest bite forces, with mean maximum bite forces ranging from 216 to 847 N, according to numerous studies that have examined maximum bite forces during mastication. Given the possibility of forces greater than 965 N during biting activities, an initial fracture resistance of 1000 N is considered sufficient for a fair clinical prognosis in the posterior region. All of the test specimens in this investigation showed load-bearing values greater than 1000 N, which suggests that they have sufficient fracture strength to withstand physiological occlusal stresses [33]. Significantly, three-unit PEEK FDP copings showed plastic deformation at 1200 N and fracture loading at 1378 N, according to Stawarczyk *et al.* [3].

Notwithstanding the encouraging outcomes, it is critical to recognize constraints. Pure PEEK presents an inherent problem, as demonstrated by Hang-ying J. *et al.*'s low susceptibility to bending fatigue. This constraint is addressed by the invention of BioHPP, a composite of PEEK and zirconium oxide, which has demonstrated *in vitro* experiments the ability to sustain loads up to 1,518 N [10]. In a comparative *in vitro* investigation, Preis V. *et al.* assessed BioHPP against Zirconium-coated lithium disilicate and discovered that BioHPP demonstrated robustness under varied stresses without breaking [1].

One important factor is PEEK's strength of binding to coating materials. PEEK and its modified form (BioHPP) exhibited superior adhesion when compared to Cr-Co alloy and metal-ceramic, according to a study by Hang-ying J, *et al.* [10]. This characteristic guarantees that PEEK structures can be covered with traditional composite materials in an efficient manner. Thus, PEEK exhibits good load-bearing properties and fracture resistance against physiological occlusal stresses; nevertheless, intrinsic limitations are addressed by the introduction of composite materials such as BioHPP. PEEK's increased mechanical qualities and adaptability make it a competitive substitute for dental prostheses, highlighting its promise for fixed dental prostheses [10, 33].

Advantages of peek in restorative dental procedures

- **Optimal elastic module:** PEEK exhibits an elastic modulus that is comparable to that of dentin and human bone, distributing stress favourably and absorbing chewing forces [23].
- **High fracture resistance:** PEEK's reduced elastic modulus reduces the probability of root fractures in post-endodontic restorations by contributing to strong fracture resistance [1].
- **Versatility in applications:** The excellent binding strength of PEEK to coating materials enables the efficient application of conventional coating composites, guaranteeing structural integrity [10].
- **Enhanced mechanical properties:** PEEK's limitations are addressed and its mechanical qualities are improved for broader applications by composite materials like BioHPP, which combine PEEK with zirconium oxide [10].

Disadvantages of peek in restorative dental procedures

- **Low resistance to bending fatigue:** PEEK's limited resistance to bending fatigue in its pure form limits its use in several situations [10].
- **Hydrophobic surface:** Because of its hydrophobic surface, PEEK presents difficulties for fixed prosthodontics; to improve adherence, surface modification methods such acid etching and plasma treatment are required [25].

Conclusion

In summary, research into PEEK in restorative dentistry has revealed a material with exceptional qualities, including a high fracture resistance, an ideal elastic modulus similar to human bone, and a variety of uses. Notwithstanding PEEK's early drawbacks, advancements such as BioHPP, which blends PEEK with zirconium oxide, solve problems and increase its mechanical capabilities for more applications. PEEK has demonstrated a strong ability to endure physiological occlusal stresses in multiple investigations. This, together with its improved bond strength to coating materials, makes it a viable substitute for permanent dental prostheses and post-endodontic restorations.

Recent developments in restorative materials demonstrate a move toward investigating sophisticated polymers, such as PEEK, because of their mechanical qualities and biocompatibility. Comprehensive clinical trials are crucial to comprehending PEEK's benefits and limitations, as highlighted by the field's ongoing research and development. Additionally, to counteract PEEK's hydrophobic tendency and provide better adherence in fixed prosthodontics, future guidelines call for improving surface modification procedures. PEEK has promising futures in restorative dentistry, particularly with the development of materials science and technology. PEEK's position as a competitive contender in the field of restorative materials is bolstered by ongoing advancements and exploration, which could lead to improved clinical outcomes and patient satisfaction soon.

Conflict of Interest
Not available

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Not available

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