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Peek Material and its Technical Consideration in Dental Application-A Systematic Review

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***Abstract*: PEEK material has been evolving as an outstanding biomaterial substitute for various dental applications such as implants, fixed and removable prosthesis, orthodontic wires, maxillofacial prosthesis and several restorative purposes. The present review was aimed to focus exclusively on the properties of PEEK and its modifications, dental applications as available in various literature studies with emphasis on its technical considerations. A structured literature search for articles written in the English language in PubMed, Medline, EBSCOhost, Science Direct, Google Scholar and Web of Science databases from 2008 till date was retrieved by using keywords PEEK in Dentistry, PEEK Dental implant, PEEK Crown, PEEK and Dental Materials, modified PEEK, Poly-ether-ether-ketone and PEEK Technical considerations. The literature review showed that the PEEK material has superior properties such as high elasticity modulus close to that of bone and dentin, biocompatibility, radiolucency and wear resistance. With several modification and reinforcement techniques it can be considered that in the future, PEEK prostheses will have an important role in routine applications and also in other specialties of dentistry.**

***Keywords*: Fixed Prosthesis, modulus of elasticity, polyether ether ketone, surface modified PEEK polymer, wear resistance.**

1. Introduction

Poly-ether-ether-ketone (PEEK) is a polycyclic, aromatic, thermoplastic, semi-crystalline, linear structured polymer obtained as a result of binding of ketone with ether functional groups between aryl rings [1]. Over the years PEEK has been evolving as a remarkable biomaterial substitute for various dental applications such as implants, fixed and removable prosthesis, maxillofacial prosthesis and even restorative purposes [2]. In dentistry, success of any material predominantly depends on its biological properties like minimizing the amount of bone loss on functional loading, minimal tissue reaction, durability, sustainability and optimum cellular response to oral environment [3]. Apart from these biological characteristics, properties such as mechanical, chemical and radiological aspects also play a vital role in overall outcome of the material used.

Several studies have been carried on its material aspect and modifications along with various different materials such as glass and carbon fibers were performed to increase its use as an alternative to metal alloys in industrial areas [4]. As a result, several substantial and technical modifications were made on this PEEK material to increase its creep resistance, enhance rigid semi-crystalline nature with bone-like toughness, biocompatibility, and superior mechanical, chemical and aesthetic properties [5]. The present review was aimed to focus exclusively on the properties of PEEK and its modifications, dental applications as available in various literature studies with emphasis on its technical considerations.

2. Methodology

A structured literature search for articles written in the English language in PubMed, Medline, EBSCOhost, Science Direct, Google Scholar and Web of Science databases from 2008 till date was retrieved by using MeSH terms “PEEK in Dentistry”, “PEEK Dental implant”’, “PEEK Crown”, “PEEK – Dental Materials”, “modified PEEK”, “Poly-ether-ether-ketone” and “PEEK Technical considerations”.

3. Results

A total of 125 articles were found based on the literature search among which 22 were not related to our study, and they were excluded. Abstracts, short communications, letter to authors and other language related literature (except English) were excluded. A concise of 103articles was found to be relevant for our study design. The data showed that the distribution of articles on the properties of PEEK was 22 (21.3%), implant-related articles were 29 (28.15%) whereas the maximum number of articles related to different prosthodontics applications were 44 (42.7%) and 8 (7.7%) articles found on the uses of PEEK in other specialties of dentistry which includes orthodontics, oral and maxillofacial surgery, and endodontics. The 44 articles which belong to prosthodontics, 23 of them are related to different Crown systems (52.2%), 7 are removable

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partial dentures (15.9%), 8 are fixed partial dentures (18.1%), and 6 were in relation to maxillofacial prosthodontics (13.6%).

4. Discussion

A. Properties of PEEK Materials

1) Physical and Chemical Properties

PEEK has superior mechanical properties with resistant to high melting temperatures and to hydrolysis. It also shows significant resistance to deterioration during various sterilization procedures due to its semi-crystalline material configuration [6]. The most important property of this material is that it has a low elasticity modulus close to the elasticity modulus of bone (3.6 GPa) that prevent bone resorption and achieve good bone remodeling however when an increase in the elasticity modulus is desired, the PEEK elasticity modulus can be brought to high levels up to 18 GPa with the addition of carbon fibers. The addition of carbon fiber makes the material even more mechanical, Chemical and thermal resistant. PEEK with its low specific weight can be used to construct very lightweight prosthesis which will provide high patient satisfaction and comfort [7].

2) Biological Properties

PEEK as a biologically inert material when examined, showed no evidence of cytotoxicity, mutagenicity, carcinogenicity or immunogenicity in the toxic form under controlled conditions [8]. In recent years, PEEK has also been modified at the Nano-level in order to improve its bioactivity and Osseo-conductive properties. Bio-HPP (High Performance Polymer), the Nano-modified form of PEEK is more advantageous for being anti-allergic in nature, non-metallic in taste, excellent polishing properties, low plaque affinity, and good wear resistance [9].

3) Aesthetic properties

Due to the greyish brown color of PEEK, it is not suitable for monolithic aesthetic restorations on anterior teeth. Hence more aesthetic material like composite should be used as a coating to improve aesthetics when used as direct or indirect restorative material rather than only as implant and framework material [10].

B. Application of PEEK in Dentistry with Technical Considerations

PEEK material has shown high biocompatibility and has become a material of choice in various dental applications such as dental implant, tooth abutment, fixed and removable prosthesis, maxillofacial prosthesis, orthodontic wires, and for restorative purposes.

1) PEEK in Dental Implants

Titanium as an implant material of choice though has satisfactory mechanical and biological properties also shows some amount of bone resorption with subsequent implant loss, disintegration under radiation light, hypersensitivity or allergic reactions, and surface deterioration leading to peri-implantitis [11]. Although titanium displays better corrosion resistance, long term and clinical observation studies have shown that titanium does not corrode when used in living tissue however galvanic coupling of titanium to other metallic restorative materials may generate corrosion. . Corrosion products have been associated with tissue reaction such as local pain or swelling in the region of the implant in the absence of infection and it can cause secondary infection. As a bio-inert material, PEEK has high stability, low density (1.32 g/cm^3) but insolubility, as Polymers possess hydrophobic surfaces with low surface energy reducing the cellular adhesion [12]. To overcome the limited bioactivity and Osseo-conductive nature of PEEK, studies were performed by blending or coating PEEK with bioactive nanoparticles like Hydroxyapatite particles (HAp), composites, Nano-filler composites, titanium oxides (TiO2) and Fluoro-hydroxyapatite crystals (HAF) using methods such as spin-coating, gas plasma etching, electron beam, and plasma-ion immersion implantation on the material surface to increase cell attachment and improve cellular response [13]. Schwitalla et al in 2013 reported that there had been insufficient studies to develop the biomechanical behavior to provide a more homogenous stress distribution of PEEK implants to the per-implant bone, and insisted the need for long-term studies of PEEK implants [8]. According to Barkarmo et al in 2014 there has been much focus on the nanoscale coating of PEEK with bioactive apatite such as spin-coating, gas plasma etching, electron beam, and plasma-ion immersion implantation [14]. Zheng Y et al in 2015 investigated the apatite coating on function surface of PEEK by introducing hydroxyl, acid and nitrate groups over the hydroxylated PEEK surface to enhance cellular adhesion, proliferation and differentiation of osteoblast cell [15]. Qahtani et al in 2015 carried out an experimental to compare the changes in wettability of original screw-type implants including PEEK after irradiation with ultraviolent rays A and C. The author observed that the PEEK implants acquire minimal hydrophilic property during irradiation with UV-C thus enhancing the interaction between the material and the surrounding tissue environment [16]. Ren et al in 2018 in an in-vitro study observed microwave assisted coating of bioactive was done amorphous magnesium phosphate (AMP) PEEK showed improved Osseo-integration than other materials [17].

2) PEEK as Abutments

Titanium, gold, zirconium and ceramics are the most preferred material of choice in the production of abutment that meets the mechanical, biological and aesthetic expectations. Titanium and alloys have several disadvantages such as corrosion, aesthetics consideration and causes hypersensitivity reactions. On the other-hand, Zirconium though aesthetically acceptable abutment tend to worn intra-orally over time and possess poor mechanical resistance [18]. The elastic property of PEEK material reduces the forces created when chewing which are interconnected to the implant, it has been reported that because of the low elastic modulus of this material, the stresses occurring both in abutment teeth and in the cement interface are reduced to a minimum. For retention load, PEEK will be a suitable material as a telescopic crown over Zirconia crowns [19].

Various reinforcements have been developed such as titanium dioxide, barium sulfate, carbon-reinforced PEEK (CFR-PEEK), and glass fiber-reinforced PEEK (GFR-PEEK) material. CFR-PEEK due to its biomechanical behavior,

decreased stress peaks, decreased elastic deformation, adaptability, excellent mechanical properties, compatibility with the imaging techniques and biocompatibility was often used in implant abutments. As a result of modification of PEEK with varying rates of carbon fiber, and glass fiber, it can be a material with advanced resistance to wear, high durability and hardness. In most cases, the application of opaque material followed by processing with acetone, phosphate-based methacrylate linings or tribiochemicals are performed to increase resistance to shear forces [20, 21].

Koch et al in 2010 compared the bone-implant contact values of PEEK, zirconium and titanium implants, and observed the PEEK implants with the lowest values. The reason for this was reported to be that PEEK is formed of a bio-inert material and thus the bone apposition potential was insufficient [22]. Becker et al in 2012 described a novel method regarding the use of prefabricated PEEK abutment screwed into the internal connection of the implant to get the proper emergence profile [23]. Balci et al in 2015 observed complete absence of breakage in 40% of prostheses applied over PEEK abutments with minimal or nil deformation in the abutment. These studies suggested that with only a change of abutment, the same prosthesis can be re-used [24].

3) PEEK Material in Fixed Prostheses:

Metal supported ceramics have been used for many years with disadvantages like corrosion, allergic potential and poor light permeability. PEEK material possess higher biocompatibility than metal-based ceramics that can be more easily repaired, does not wear down within the mouth and no deterioration is seen in the material properties during processing, thus increasing the possibility of its use as crown material [25]. Beuer et al in 2008 observed the fracture resistance of PEEK is higher than zirconia and ceramics, and PEEK can be modified easily by incorporation of other materials [26].

4) PEEK Material in Restorations

The bioactive Nano-composites can be used as indirect intra-coronal or extra-coronal restorations. One of the major advantages of PEEK material is that it can bind to Light polymerizing indirect composites. In resin-bonded bridges produced from PEEK material, there is a minimal need for holding elements and retentive abrasions as in metal ceramic resin-bonded prostheses. In the use of PEEK material as a temporary abutment, high bonding is required between composite resins in the formation of the gingival tissue emergence profile and the gingiva shaping. To achieve good bonding between PEEK and restorative materials, surface energy is increased using traditional sanding, roughening with acid, plasma spray and laser roughening methods [27]. Wang et al in 2015 demonstrated the melt-bending of bioactive nanoparticles with PEEK materials to improve their mechanical and bioactive properties [28]. Rocha et al in 2016 reported that sulfuric acid only or a mixture of sulfuric acid and hydrogen peroxide can be used to roughen the PEEK surface and with sanding on the PEEK, the surface area and wettability can be increased [29]. Nazari et al in 2016 showed that composite-coated PEEK had lower fracture resistance to occlusal forces than metal ceramic and zirconium restorations. Furthermore, the fractures in the PEEK restorations were seen to be between the PEEK substructure and the composite veneer [30].

5) Various other applications of PEEK:

PEEK can be used as aesthetic orthodontic wire as similar orthodontic forces are obtained in comparison with titanium-molybdenum (Ti-Mo) and nickel-titanium (Ni-Ti) wires [31]. Costa-Palau et al in 2014 reported that, the fabrication of maxillary obturator for a patient with oro-nasal defect using PEEK as an alternative to conventional materials and methods and claimed that the PEEK obturator is weightless, biocompatible, with good retention and ease of polishing [32].

6) Key points obtained from the review

- PEEK possesses high elasticity modulus close to that of bone and dentin, which can also be further increased by incorporation of carbon fibers, thus functioning as an excellent choice of the material in implant and other fixed prosthesis.
- PEEK can be blended with or coated with bioactive nanoparticles to improve bioactivity. Bio HPP can be considered as a good alternative material for abutments with decreased periodontal support when replacing distal extension situations.
- PEEK, as a radiolucent material has significant role in the evaluation of both osseo-integration and of the tissue surrounding the implant on computed tomography (CT) imaging and also reduces magnetic resonance imaging (MRI) artifacts.
- It can be considered that increasing the bonding of the PEEK material with acrylic and composite resins and developing the osseo-integration properties will further increase dental applications.
- With several modification and reinforcement techniques it can be also deliberated that in the future, PEEK prostheses will have an important role in routine applications and also in other specialties of dentistry.

5. Conclusion

This paper presented an overview of Peek material and its technical consideration in dental application-a systematic review.

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