Modified Bioactive Peek Material for Dental Implants : A Review

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Abstract:-

- ***Backround:***

Polyetheretherketone (PEEK) have been emerging as an excellent biomaterial substitute for metal based implants due to its chemical resistance, rigid semi-crystalline nature with bone-like toughness, greater biocompatibility, and superior mechanical properties.

- ***Aim:***

The present evaluation of the available literature search is to provide a broad review on properties and bioactivity of PEEK material with emphasis on modified PEEK dental implants to overcome its limited bioactivity as a material of choice.

- ***Study Selection:***

A structured literature search for articles written in the English language in PubMed, MEDLINE, Embase, Google Scholar and Web of Science databases from 2000 till date was retrieved by using MeSH terms “Dental implant ”, “PEEK Dental implant”', “PEEK crown”, “Osseo-integration”, “PEEK”, “Poly-ether-ether-ketone” and “implant materials”.

- ***Observations:***

PEEK possesses compound structure with promising aesthetics and functional properties. Surface modifications of PEEK with Hydroxyapatite (HA), Fluoro-hydroxyapatite crystals (HAF) showed superior Osseo-conductive property along with antibacterial effect. TiO2 coatings on PEEK implant induced new bone formation more prominently with increase in shear bond strength of bone. Numerous studies have shown less wear resistance of carbon fiber (CFR-PEEK) or glass fiber reinforced (GFR-PEEK) PEEK material during mastication and brushing than Titanium based implants.

- ***Conclusion:***

Considering the long term clinical success of implant prosthesis, reinforced-PEEK material could be a potent alternative to titanium in high stress situations such as bruxism, excessive crown height space and in allergic responses.

Keywords:- *Fiber-Reinforced Polyetheretherketone; Melt-Blending; Nano-Hydroxyapatite; Osseo-Integration; Peri-Implantitis.*

I. INTRODUCTION:

Response of a tissue after placement of an implant biomaterial can either be a formation of bone providing attachment to the alveolar bone with the implant surface commonly known as osseo-integration or a scar fibrous tissue bringing about the failure of implant [1, 2]. Over the years titanium and its alloys were used a material of choice due to its high corrosion resistance, biocompatibility and passivation effect. However titanium has been revealed to exhibit high MOE (modulus of elasticity) compared to bone, resulting in failure of implant due to insufficient stress shielding, periodontal bone loss, and fracture of implants. Similarly trigger of hypersensitivity reactions, wear debris, ion leakage, and compromised aesthetics can also be an added burden with usage of this titanium based dental implants [3, 4].

Many clinical studies and researches have been carried out to identify substitutes for titanium based implant materials such as zirconia which has superior aesthetics, high modulus of elasticity, biocompatibility, low plaque affinity, good initial bone healing and low temperature degradation [5]. Although many in-vitro and in-vivo studies have shown zirconia dental implants as the potential to become alternative to titanium dental implants, there is no valid scientific data obtainable in the literature to recommend the clinical use of zirconia routinely [6]. Polymeric compounds such as Polyetheretherketone

(PEEK), a thermoplastic compound developed in 1978 [7] have been emerging as an excellent biomaterial substitute for metal based implants during construction of the implant body, abutment, and framework due to its chemical resistance, rigid semi-crystalline nature with bone-like toughness, greater biocompatibility, and superior mechanical properties [8, 9]. PEEK biomaterials in orthopedics are currently during a period of consideration and conservative adoption. the normal metal, ceramic, and polymer implants currently used for total hip and knee replacement are perceived by many surgeons and patients as reasonably successful, with survival rates within the elderly population exceeding 90% at ten years [10,11]. Only within the past decade animal studies and clinical data have started gradually accumulating to demonstrate the viability of composite stems incorporating PEEK biomaterials as an alternate to monolithic metal alloys in hip stems [12,13]

The present article summarizes the properties and bioactivity of PEEK material with emphasis on various methods recommended for enhancement of surface and body of PEEK material to overcome its limited biological property for dental implant applications.

II. PROPERTIES OF PEEK:

Polyetheretherketone (PEEK) is a semi-crystalline, organic synthetic tooth colored polymer with excellent aesthetics, chemical resistance, and superior physical, biomechanical properties than zirconia and titanium implant material. In its reinforced form, young’s modulus of carbon (18 GPa) or fiber (12 GPa) PEEK is close to the cortical bone hence preventing excessive stress shielding as seen in case of titanium [14]. PEEK crystals contains very fine lamellae that under certain conditions can organize into larger spherulites [15].The thickness of lamellae also the size and density of spherulites, depends on the processing conditions from the melt[16]. The lamellar thickness of melt-crystallized PEEK is extremely small, only 50 and 60 Å [16], like 10-12 aryl groups. Spherulites are orders of magnitude larger, about 25 to 40 µm in diameter [16]. The spherulitic microstructure of PEEK are often visualized using scanning microscopy with suitable etching [17], or by polarized light microscopy [15,16]. Depending upon the nucleation density and processing conditions, it's going to not be possible to spot individual spherulites using polarized light microscopy. Instead, the morphology under polarized light may have the looks of a “fine grained mosaic structure” of crystalline domains with varying birefringence [18].

Stress caused by screw joint interface to the implants from an ill-fitting prosthetic framework produces constant shear load on the implant, influencing the prosthesis to fracture. Often, loosening of the screw(s) on the supra-implant component precedes implant fracture and may be a sign that the framework needs to be evaluated. However, the grade of ill-fitting may be due to random distribution of the force, as a result presents as an independently-acting additional load factor. As a bio-inert material, PEEK has high stability, low density (1.32 g/cm3) but insolubility, as polymers possess hydrophobic surfaces with low surface energy reducing the cellular adhesion [19, 20]. This is often neutralized by surface modification, coating or blending with bioactive particles. PEEK features a water solubility of 0.5 w/w%, but as mentioned above isn't chemically damaged by long-term water exposure, even at temperatures of up to 260°C [21,22,23].Although PEEK itself isn't vulnerable to hydrolysis, concerns are raised that interface between the polymer and reinforcements, like carbon fiber, could also be susceptible to fluid environments in vivo [24].

III. MODIFIED PEEK MATERIAL

PEEK material can be either surface modified or combined with bioactive particles to increase the hydrophilicity, osseo-conductive properties and surface roughness. Various reinforcements have been developed such as 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 the orthopedic implants during articular joints replacement surgeries [25].

To overcome its restricted bioactivity, nano particle materials such as hydroxyapatite particles(HAp), composites, nano-filler composites, titanium oxides and fluoro-hydroxyapatite crystals (HAF) were blended with PEEK to enhanced mechanical properties and osseous induction. Surface modification improves the surface contact angle with the implant material along with significant osseo-conduciveness as seen in combined bioactive PEEK-nano-composites. Four processes have been established to nano-modify the surface: a) spin-coating, b) electron beam deposition, c) gas plasma nano-etching, and d) plasma-ion immersion. Spin-coating involves the deposition of a thin layer of nano-HAp, precipitated in surfactants and aqueous solution of calcium nitrate and phosphoric acid, on the implants [26]. A thin titanium layer deposited on PEEK using electron beam deposition has been shown to promote cellular adhesion with increased surface wettability [27]. When a titanium coating on PEEK produced by beam deposition is anodized, it's converted into a uniformly thick (2 µm), crack-free, and highly nanoporous layer of titanium dioxide (nTiO2) which may be used to carry BMP-2[28]. .Many published in vitro and in vivo studies show that BMP-2 may be a protein which plays a serious role in differentiation of stem cells to osteoblasts[29,30].

In nano-etching, surface roughness can be achieved by treating PEEK with low power plasma gases such as ammonia, oxygen, argon and water vapor [31]. Repeated pulsed with negative voltages accelerates the plasma ions to get deposited or immersed onto the substrate’s surface [32]. Chemical modifications such as sulfonation, amination, and nitration also improve the biocompatibility to achieve early osseo-integration [33].

On the other hand, PEEK material blended with hydroxyapatite particles (PEEK-HAp composites) have shown poor mechanical and bonding properties whereas titanium oxides coatings used instead of HAp, increased the rate of differentiation and proliferation of osteoblast, thus enhancing the osseo conductive property. Wang et al in an experimental study demonstrated the antibacterial properties of PEEK/nano-HAF implants specifically against streptococcus mutans, a pioneer bacterium in gingival and periodontal disease [34]. This process of combination can be achieved by melt-bending at temperature around 350 to 450 degree Celsius under 35-40MPa followed by air-cooling to 150 degree Celsius for 10minutes [35].

IV. CLINICAL STUDIES

Hufenbach et al in 2008 evaluated the deformation behavior and osteosynthesis nature of carbon fiber reinforced (CFR-PEEK) implant structure and observed superior mechanical behavior and binding than titanium implant material [36]. Santing et al in 2012 performed an in-vitro study to evaluate the fracture strength of implant supported composite resin crown fabricated over PEEK abutments and observed better fracture strength in the anterior regions compared to Ti implants [37]. Lu et al in 2014 assessed the nanostructure of titanium oxide coated CFR-PEEK material and observed nanopores were formed with the side wall and bottom embedded with TiO_2 nanoparticles on the CFR-PEEK. Biochemical properties such as cellular adhesion, proliferation, and osteo-differentiation were superior compared to Ti implants [38]. In 2014, Rochford et al proposed that oxygen plasma treated PEEK implants promotes the osteoblastic activity and adhesion of blast cells with the implant surface even in presence of microbes [39].

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 [40]. Wu et al and Wang et al in 2015 demonstrated the melt-bending of bioactive nanoparticles with PEEK materials to improve their mechanical and bioactive properties [33,34]. 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 [41].

Sampaio et al in 2016 conducted micro-scale abrasion tests were using different weight contents of hydrated silica to compare the abrasive wear resistance of PEEK and $Ti6Al4V$ and reported higher volume loss rate and less wear resistance by PEEK compared to $Ti6Al4V$ [42]. SimilarlyZoidis and Papathanasiou had also showed PEEK has an advantage over metal ceramics or ceramics in dampening the occlusal forces due to low modulus of elasticity and possess reducing de-bonding rates [43].

Bubik et al in 2017 reported decreased viability and cell adhesion on PEEK in human fetal osteoblasts cell culture study. This could be attributed to the polished PEEK surface thus preventing osteoblast attachment [44]. Montero et al in 2017 evaluated the influence of different sulfonation degree on the biofilm growth and observed antibiofilm compound associated with antibacterial property prevents infections of the PEEK implant thus preventing loss of implant or any tissue reaction [45]. Rea et al in 2017 performed an in-vivo study to evaluate the marginal soft and hard tissue healing at titanium and PEEK healing implant abutments. The author observed resorption of the buccal bone crest was higher at abutment with the PEEK bonded to titanium base compared to titanium material alone [46]. 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 [47]. Wenz et al. using mouse fibroblasts [48]. A 30% PAN carbon-fiber reinforced composite PEEK material (LNP Corporation) was evaluated. After 96h of exposure to PEEK, the cell culture was healthy and didn't appear different than negative controls. The authors concluded that the PEEK composite exhibited “excellent” in vitro biocompatibility during this cell culture model. Genotoxicity testing was performed by Katzer et al [49].The Ames test was selected to guage PEEK 381G resin for mutagenicity. These tests confirmed that PEEK wasn't mutagenic.

V. OBSERVATION:

PEEK possesses compound structure with promising aesthetics and functional properties. Numerous studies have shown less wear resistance, better stress distribution, minimal deformation behavior of carbon fiber (CFR-PEEK) or glass fiber reinforced (GFR-PEEK) PEEK material during mastication and brushing due to structure of PEEK allowing the optimized distribution of masticatory forces around the implant when compared to the titanium based implants. Studies have also shown lower fracture resistance of PEEK with most of fracture occurring at the neck of the abutment screw.

Surface modifications of PEEK with hydroxyapatite (HAp), fluoro-hydroxyapatite crystals (HAF) showed superior osseo-conductive property along with antibacterial effect. TiO_2 coatings on PEEK implant induced new bone formation more prominently with increase in shear bond strength of bone. Ability of fluorinated PEEK to enhance the osseo integration and bacteriostasis stabilizes dental implants thus preventing peri-implantitis. Nanoparticle modified PEEK materials have improved hydrophilicity, which leads to better cellular proliferation because the dental implant surface with the lower biomaterial surface tension influences the interaction between the material and the surrounding physiological environment. Surface treatment or coating with amorphous magnesium phosphate (AMP) on PEEK material can enhance formation of new bone and promotes osseointegration [50,51].

VI. CONCLUSION:

Considering the long term clinical success of implant prosthesis, reinforced-PEEK material or surface modifications with nanoparticles could be a potential alternative to titanium especially in high stress situations such as bruxism, excessive crown height space and in allergic responses. Very few clinical trials have been done to establish PEEK as dental implant material, however it is too early to draw a conclusion that PEEK material either in reinforced or surface modified form can replace titanium based implants in the near future. Further research and more number of controlled clinical trials on PEEK implant material are required specifically for construction of implant abutment and implant body.

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